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EXTRA-EXPERIMENTAL INTERFERENCE AND THE RETENTION OF WORDS[1]

LEO POSTMAN

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This paper reports a series of studies designed to explore extra-experimental sources of interference in the forgetting of verbal materials. When a naive *S* learns a single rote series, retention losses after an interval of time may be attributed to interference from verbal habits practiced outside the laboratory. Extra-experimental interferences may be proactive or retroactive. As Underwood (1957) has pointed out, major weight must be given to proactive rather than retroactive effects since the opportunities for acquiring verbal habits which become sources of interference are clearly greater prior to the experiment than during the limited time intervals typically used in studies of retention.

Experimental analysis of the conditions of extra-experimental interference requires specification of the verbal habits which are assumed to compete with the prescribed responses at the time of the retention test. In a recent theoretical account by Underwood and Postman (1960) two major sources of extra-experimental interference were distinguished, viz., (*a*) letter-sequence interference, and (*b*) unit-sequence interference. Linguistic usage outside the laboratory establishes transitional probabilities among sequences of letters as well as hierarchies of associations among verbal units *qua* units. Letter-sequence interference will occur to the extent that the sequences of letters making up the units in the experimental list deviate from those characteristic of the language, i.e., the amount of such interference will vary inversely with the probability of the prescribed sequences in the language. Unit-sequence interference will result when the sequence of units (e.g., syllables, words) in the list fails to conform to the associative habits established outside the laboratory. The amount of unit-sequence interference should increase with the frequency of occurrence of the units in the language. The more frequently the units are used the more likely they are to have strong associates which will interfere with the sequences reinforced in the experiment.

This conception of the sources of extra-experimental interference has testable implications for the relationship between meaningfulness and retention. The dimension of meaningfulness may be

[1] This research was supported by a grant from the National Science Foundation. The writer is grateful to Audrey Bohm, Karen Updegraff, and Margaret Boyer for their assistance.

represented by an arrangement of verbal units along a continuum extending from the least probable letter sequences to the most frequent words. Extra-experimental habits generate two intersecting gradients of interference which may be plotted against this continuum. The gradient of letter-sequence interference is at its maximum at the low end of the continuum and declines as the probability of letter-sequences increases. The gradient of unit-sequence interference rises as a function of the frequency of occurrence of the items as integrated verbal units and reaches its maximum at the high end of the continuum. Thus, interference is expected to be maximal for items at the two extremes of the continuum; it should be minimal for items toward the center which represent common sequences of letters but lack strong associations with other verbal units.

The conditions of extra-experimental interference are assumed to conform to the A-B, A-C paradigm used in formal studies of retroactive and proactive inhibition. The paradigm applies to both letter-sequence and unit-sequence interference. In the former case, the critical associations are among the letters within the individual units; in the latter case, between successive units. In both cases, acquisition of the prescribed association, A-C, will require the unlearning or extinction of a pre-experimental association, A-B. Evidence obtained in studies of interserial interference, and particularly in experiments using the method of modified free recall (Briggs, 1954; Underwood, 1948) makes it reasonable to assume that the extinguished habit, A-B, will recover as a function of time and compete with A-C at the time of recall and relearning. If the old habit is practiced after the end of the experiment, as is likely with popular linguistic associations, the process of recovery is speeded up. Retroactive and proactive effects may thus summate in producing extra-experimental interference with the retention of the prescribed list.

The results of a study by Underwood and Postman (1960) give some support to this analysis. Retention was compared for four kinds of three-letter units: high-frequency words, high-frequency trigrams, low frequency words, and low-frequency trigrams. At each of the two levels of frequency, the probabilities of the letter sequences in words and trigrams were closely equated. A test of recall one week after learning showed only small differences in retention loss. Contrary to the usual assumption, meaningfulness did not favor retention. As measured by relearning to criterion, high-frequency trigrams were retained better than any of the other materials. Since both letter-sequence and unit-sequence interference are assumed to be minimal for high-frequency trigrams, this finding lends direct support to the present hypothesis. The pattern of errors was likewise in accord with theoretical expectations. Errors reflecting letter-sequence interference recovered more rapidly for the low-frequency than the high-frequency lists; the recovery of intralist errors attributable to unit-sequence interference was greater for lists of words than lists of trigrams.

The experiments reported in this paper focus on the operation of the gradient of unit-sequence interference in the retention of words. In the study of Underwood and Postman, the two lists of words differed greatly not only with respect to their frequency of occurrence in the language but also with respect to the probability of their letter sequences. In the present experiments, two-syllable nouns of high and low frequency of occurrence were used but there were no comparable differences in the probabilities of the letter sequences of which the two sets of words were composed. Forgetting, therefore, could be considered largely a matter of unit-sequence interference. In Exp. I the course of retention for the two kinds of materials was measured over a one-week interval by the method of serial anticipation. Since the results of

that experiment failed to show superior retention of the high-frequency lists, the question arose as to whether a paced anticipation test masks a greater availability of high-frequency responses at recall. In order to explore this possibility, retention for the same materials was tested by the method of free recall in Exp. II. A mixed list, composed of words of high and low frequency in equal proportions, was used in Exp. III to test an implication of the hypothesis of unit-sequence interference. We assume that the probability of strong pre-experimental associations among the items to be learned varies directly with the number of high-frequency words in the list. Thus, the number of such associations converging on any one high-frequency item should be smaller in a mixed list than in a homogeneous list. The question investigated in Exp. III was whether the reduction in the number and strength of pre-experimental associations would lead to a shift in relative retention scores in favor of the high-frequency items.

Experiments I and II

Method

Materials.—The materials used in the construction of the experimental lists consisted of 48 two-syllable nouns. There were two groups of 24 nouns each, sampling the extremes of the frequency range in the Thorndike-Lorge word count (1944). For the low-frequency words, the number of occurrences in the "L" count was between 1 and 3 in 4.5 million; for the high-frequency words the number of occurrences ranged between 1000 and 3300. At each level of frequency, two 12-word lists were constructed which are presented in Table 1. In addition to the word frequencies, the table shows the mean frequency of the successive trigrams formed by the letters in each word. For a word composed of n letters, n-2 such trigrams can be formed. The trigram count (Underwood & Schulz, 1960) gives the number of occurrences in 1,035,000 words. Mean trigram frequencies correlate with the word frequencies but there is considerable overlap between the values for the two sets of words. The mean trigram values are relatively high even for the low-frequency words: all but two fall into the upper third of the total distribution of trigram frequencies. Thus, letter-sequence interference may be assumed to be negligible for all the lists. Table 1 also shows the mean familiarity ratings and m-values for each word. The latter two scores were obtained in a standardization study conducted by the writer.[2] The ratings represent the mean judgments of 1000 students at the University of California who rated the familiarity of each word on a 5-point scale, with 1 denoting minimal familiarity and 5, maximum familiarity. The m-values were obtained by a method similar to Noble's (1952) and represent the mean number of different associations given to each word by a sample of 96 *Ss* during a 50-sec. interval. While the criterion for selection of the words was frequency of occurrence, the differences between the means of the ratings and m-values are consistent with the classification based on the word count. It should be noted that there is closer agreement between the word-frequency count and rated familiarity than between either measure and the value of m. Thus, there is some overlap between the two sets of words with respect to m-value but not the other two indices.

Two different serial orders were used with each of the 12-word lists. Thus, there were four different lists at each level of frequency. The different lists were used equally often under all conditions of the experiment.

Experiment I Procedure and Ss.—The lists were presented on a Hull-type memory drum at a 2-sec. rate, with an intertrial interval of 6 sec., and learned by the anticipation method to a criterion of one perfect recitation. Retention was tested by relearning to the same criterion. There were three retention intervals—30 sec., 2 days, and 7 days after the end of original learning. The 30-sec. test provides an empirical estimate of associative strength at the end of practice.

With two kinds of lists and three retention intervals, there were six groups of 16 *Ss* each. The *Ss* were undergraduate students at the University of California and were assigned to the conditions by means of a table of random numbers, with restriction to equal *Ns*. All *Ss* had English as their native language and were naive to rote-learning

[2] The complete results of the standardization procedures will be presented in a forthcoming publication.

TABLE 1

WORDS USED IN THE EXPERIMENT

List I					List II				
Item	Word Freq.[a]	Mean Trigram Freq.[b]	Mean Familiarity Rating	m-Value	Item	Word Freq.[a]	Mean Trigram Freq.[b]	Mean Familiarity Rating	m-Value
High-Frequency Words									
Answer	2132	131	4.73	8.37	Business	2850	309	4.51	9.49
Building	1014	337	4.64	9.83	Country	1714	156	4.40	10.65
Color	1541	49	4.56	10.99	Dinner	1266	126	4.90	10.51
Doctor	1631	125	4.32	9.96	Figure	1202	126	4.61	9.05
Garden	1036	152	4.23	12.01	Letter	1748	483	4.68	9.99
Husband	1788	253	4.45	8.83	Morning	2015	417	4.83	10.30
Moment	2396	619	4.44	7.39	Order	1477	220	4.53	8.33
Office	1640	112	4.43	9.72	Problem	1079	236	4.65	8.68
Paper	1235	190	4.85	10.81	Reason	1121	261	4.64	7.17
Story	1651	310	4.40	9.40	Shoulder	1135	337	4.23	9.49
Trouble	1180	182	4.49	7.76	Table	1325	288	4.73	10.56
Window	1564	148	4.70	9.86	Woman	2431	181	4.84	8.88
Low-Frequency Words									
Abbess	3	192	1.92	4.71	Bramble	3	134	2.13	7.04
Buffoon	2	54	2.17	6.45	Curfew	2	57	3.75	8.60
Caucus	1	59	2.64	7.50	Dotage	1	101	1.77	5.01
Decoy	2	47	3.30	7.59	Farthing	2	244	2.16	6.29
Gullet	2	119	2.35	5.94	Harem	2	284	2.86	8.01
Mermaid	3	78	2.91	10.01	Lorry	3	53	1.63	5.88
Oboe	1	2	2.51	8.48	Monsoon	2	98	2.52	8.50
Prefix	2	106	3.68	7.35	Oxide	1	119	3.53	7.69
Ramrod	2	38	2.60	6.75	Pestle	3	289	2.00	5.52
Sequel	3	72	2.76	6.60	Stanza	3	164	3.25	8.36
Tortoise	2	127	2.85	9.18	Tenure	3	191	2.54	7.02
Wicket	3	122	2.34	6.90	Wampum	1	10	2.36	7.63

[a] Occurrences in 4.5 million words.
[b] Occurrences in 1,035,000 words.

experiments. Two *Ss* were replaced because of failure to learn, both of them in the 30-sec. group of the low-frequency condition. On the basis of a postexperimental inquiry *Ss* who admitted to deliberate rehearsal during the retention interval were discarded and replaced. The criteria of deliberate rehearsal were (*a*) three or more attempts at oral recitation, and (*b*) one or more attempts at written reproduction. In the 2-day groups seven *Ss* learning a high-frequency list and six *Ss* learning a low-frequency list were replaced; in the 7-day groups there were three discarded *Ss* in the high-frequency condition and two in the low-frequency condition. In view of the possibility that *Ss* who rehearsed might differ in ability from those who did not, *Ss* in the 30-sec. groups were retested after 7 days, and those who admitted to rehearsal were likewise replaced. There were five such cases in the high-frequency group and four in the low-frequency group. As it turned out, there was no apparent difference between rehearsers and nonrehearsers as measured by trials to criterion and performance on the 30-sec. test.

Experiment II Procedure and Ss.—The materials and conditions of learning in Exp. II were exactly the same as in Exp. I. The two studies differed, however, with respect to the method of measuring retention. In Exp. II, a 5-min. test of free recall was used. The *Ss* were instructed to call out the words in any order that occurred to them and were encouraged to guess if they were uncertain about an item. Rate of response was recorded

by *E* with the aid of a timer which flashed a light every 10 sec. Two retention intervals were used—30 sec. and 7 days.

With two kinds of lists and two retention intervals, there were four groups of 16 *Ss* each. The *Ss* were assigned to the conditions by means of a table of random numbers, with restriction to equal *N*s. All *Ss* had English as their native language and were naive to rote-learning experiments. One *S* in the 7-day group learning the high-frequency lists was discarded and replaced because of deliberate rehearsal. No *Ss* were lost because of failure to learn.

Results

Original learning.—There were no significant differences among the groups in the two experiments learning a given kind of material. There were also no significant differences among the different lists used at each level of frequency. The data on original learning obtained in the two experiments have, therefore, been combined. The results for the two types of list are thus based on 80 *Ss* each (48 *Ss* in Exp. I and 32 *Ss* in Exp. II). The mean number of trials to criterion was 18.24 ($SD = 7.32$) for the high-frequency lists, and 24.08 ($SD = 9.61$) for the low-frequency lists. This difference is highly significant ($t = 4.36$, $P < .001$).

For purposes of assessing the conditions determining speed of acquisition, it is convenient to divide the total learning period into an integrative stage and an associative stage (Underwood & Postman, 1960; Underwood, Runquist, & Schulz, 1959). During the integrative stage the items in the list become available to *Ss* as responses; during the associative stage the responses are connected with the prescribed stimuli, e.g., the preceding items in a serial list. The duration of the integrative stage is estimated by the number of the trial on which the correct response is first given anywhere in the list. The length of the associative stage is measured by the number of trials between the end of the integrative stage and the first occurrence of the correct sequential association. The results of such a stage analysis for the two kinds of lists are shown in Table 2. The integrative stage is significantly shorter for the high-frequency lists ($t = 4.95$, $P < .001$). There is no comparable difference in the length of the associative stage. The mean number of trials separating first appearance of the response from the first correct placement is 2.06 for the high-frequency lists, and 1.83 for the low-frequency lists. This difference in favor of the low-frequency condition is not significant ($t = .96$). It appears that the difference in speed of learning is attributable primarily to the greater availability of the high-frequency responses. The fact that the advantage of the high-frequency items in the first stage of learning does not carry over into the second stage is consistent with the assumption that unit-sequence interference varies directly with meaningfulness. This assumption finds additional support from an analysis of the overt errors during learning.

Overt errors during original learning. The mean number of overt errors per trial during the acquisition of the high-frequency lists was 1.54

TABLE 2

MEAN TRIAL NUMBER ON WHICH RESPONSES WERE FIRST GIVEN AND FIRST PLACED CORRECTLY DURING ORIGINAL LEARNING IN EXP. I AND II

Word Frequency	First Given		First Placed	
	Mean	*SD*	Mean	*SD*
High	4.42	1.52	6.48	2.56
Low	5.93	2.25	7.76	2.85

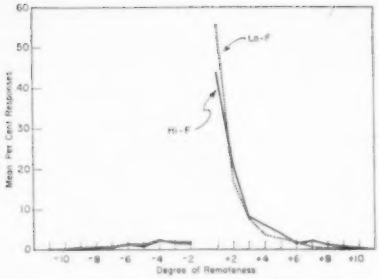

FIG. 1. Mean percentages of intralist errors of different degrees of remoteness during acquisition of lists of high and low word-frequency.

(SD = .62), and 1.14 (SD = .47) during the acquisition of the low-frequency lists. This difference in error rate is highly significant (t = 4.54, $P < .001$). Thus, speed of learning and rate of overt errors vary together as a function of frequency. The vast majority of the errors consisted of misplaced responses from within the list. The mean percentages that such intralist errors were of all the overt errors were 95.5 for the high-frequency lists and 92.6 for the low-frequency lists.

Figure 1 shows the mean percentages that errors of different degrees of remoteness are of the total numbers of errors. Since our concern here is with a comparison between the two types of materials, we have not corrected the percentages for opportunities, but such a correction would not change the basic relationships shown in Fig. 1. A clear separation between the two lists is brought out by the percentages of errors of the first degree of remoteness. Such associations account for the largest number of intralist errors under both conditions but the mean percentage is significantly larger for the low-frequency list (t = 4.56, $P < .001$). Correspondingly, the percentages of errors of higher degrees of remoteness are larger for the high-frequency lists. On the assumption that the proportion of errors of the higher degrees of remoteness reflects the probability of pre-experimental associations, the difference between the distributions of errors points to greater unit-sequence interference during the acquisition of the high-frequency lists.

Recall.—Figure 2 shows the amounts recalled by the various groups in Exp. I. We note first the difference in favor of the high-frequency list 30 sec. after attainment of the criterion. This fact supports Underwood's (1954) conclusion that the amount of post-criterial drop is related inversely to the speed of learning. Recall decreases significantly as a function of the Retention Interval (F = 31.96, df = 2/90, $P < .001$). The over-all effect of Material is not significant (F = 1.04). Although the drop appears to be steeper for the high-frequency list, the Retention Interval × Material interaction is not significant (F = 1.19). We conclude, therefore, that there is no difference in the rate of forgetting as measured by recall. The failure to find better retention of the high-frequency list is noteworthy in itself in view of the

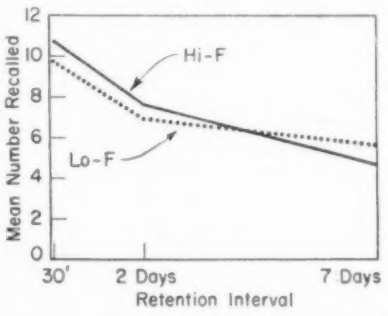

Fig. 2. Mean numbers of items recalled as a function of word-frequency and retention interval.

TABLE 3

MEAN RECALL SCORES IN EXP. I FOR ORIGINAL SAMPLE AND AFTER REPLACEMENT OF REHEARSERS

Retention Interval	High Frequency				Low Frequency			
	Original Sample		After Replacements		Original Sample		After Replacements	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
30 Sec.	10.88	1.62	10.75	1.64	9.62	2.14	9.81	2.10
2 Days	8.62	2.70	7.56	2.96	7.94	2.45	6.94	2.68
7 Days	5.44	2.95	4.62	2.59	5.31	3.29	5.56	2.92

difference in speed of learning. Thus meaningfulness favors learning, but not retention.

The effects of rehearsal.—The treatment of *Ss* admitting to deliberate rehearsal presents a methodological problem in the conduct of retention experiments. In the present study such *Ss* were eliminated from all groups. It is useful to compare the results obtained on this basis with those yielded by the original sample, i.e., when no *Ss* are replaced because of rehearsal. Such a comparison is presented in Table 3. The differences between the two sets of recall scores are not large. On the 2-day test the means for both lists increase by an equal amount when the original sample is used. On the 7-day test there is a slight shift in favor of the high-frequency list. Analysis of variance yields the same result for both sets of scores, i.e., no significant difference in the rate of forgetting. It appears that the exclusion of *Ss* admitting to rehearsal has no material effects on the experimental conclusions, at least under the conditions of the present study.

Relearning.—The mean numbers of trials to relearn to a criterion of one perfect recitation are presented in Table 4. The results are fully consistent with those of the recall test. There is a significant increase in the number of trials as a function of the Retention Interval ($F = 10.15$, $df = 2/90$, $P < .001$). While the increase is somewhat greater for the high-frequency condition, the Materials × Retention Interval interaction again is not significant ($F = 1.48$), i.e., there is no reliable difference in the rate of forgetting as measured by the speed of relearning.

Errors at recall and in relearning.—Analysis of the conditions of unit-sequence interference leads us to expect greater recovery of intralist errors for the high-frequency than the low-frequency list. Figure 3 shows the frequency of intralist errors at recall. Separate functions are plotted for errors of the first degree of remoteness and those of higher degrees of remoteness. Both types of errors are more frequent during the recall of the high-frequency lists but the difference is especially pronounced for the errors of higher degrees of remoteness. Since a large proportion of *Ss* in the 30-sec. groups made no errors, the following procedure was used to evaluate the significance of the temporal trends. Each *S* in the 2-day and 7-day groups was matched with

TABLE 4

MEAN NUMBERS OF TRIALS IN RELEARNING TO CRITERION (EXP. I)

Retention Interval	High Word-Frequency		Low Word-Frequency	
	Mean	*SD*	Mean	*SD*
30 Sec.	2.31	1.65	3.44	3.39
2 Days	4.44	2.87	6.62	4.00
7 Days	6.62	3.40	6.06	2.80

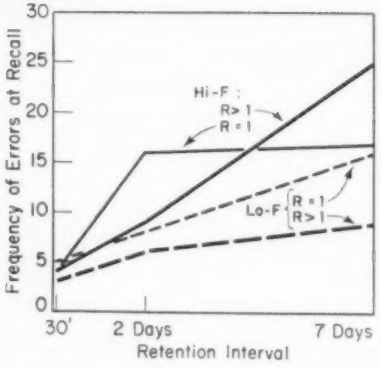

FIG. 3. Numbers of intralist errors during recall of the high- and low-frequency lists. R = 1 designates errors of first degree of remoteness, R > 1 refers to errors of higher degrees of remoteness.

an *S* in the 30-sec. group. Matching was by subgroups learning the same list and at random within subgroups. For each pair the difference in the number of intralist errors was determined, and the distributions of difference scores were subjected to an analysis of variance. The difference as a function of Material is significant ($F = 5.07, df = 1/60, .02 < P < .05$), indicating a differential rate of recovery. The difference between the 2- and 7-day intervals is also significant ($F = 5.80$), but the Retention Interval × Material interaction is not ($F < 1$), i.e., there is no reliable divergence in the error scores between 2 and 7 days.

Figure 4 shows the mean number of errors per trial in relearning to criterion as a function of the retention interval. Here a clear separation between the two conditions occurs only on the 7-day test. The Retention Interval × Material interaction is significant ($F = 3.22$, $df = 2/90$, $.02 < P < .05$). Both analyses agree in indicating more rapid recovery of unit-sequence interference for the high-frequency lists. It is important to note, however, that the number of importations from outside the list was negligible. Thus, it appears that there is differential recovery only of those pre-experimental associations which exist among items within the list.

Correlation between length of associative stage and retention.—It is reasonable to assume that the length of the associative stage during learning varies with the degree of unit-sequence interference. The hypothesis that forgetting is related to the recovery of unit-sequence interferences implies that in a distribution of *S*s the length of the associative stage should be negatively correlated with the amount recalled. For the high-frequency lists the product-moment correlation between the length of the associative stage, as defined earlier, and the amount recalled is −.34 after 2 days and −.53 after 7 days. The latter coefficient is significant at the .05 level for $N = 16$. For the low-frequency lists the corresponding values of r are .08 and −.21. There is a clear inverse relationship only for the high-frequency lists which are assumed to

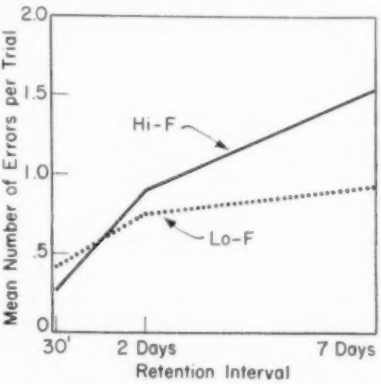

FIG. 4. Mean numbers of intralist errors per trial in relearning to criterion.

be more subject to unit-sequence interference.

Free recall.—We now turn to the results of the test of free recall in Exp. II. The mean cumulative numbers of responses obtained during the 5-min. test are plotted in Fig. 5. Recall of both lists is virtually perfect after 30 sec. The amount retained after 7 days is substantially larger than that obtained on the anticipation test in Exp. I. The mean retention loss is only 2 items. The rate of recall is, however, considerably slower after 7 days than at the end of learning. The delayed test, like the immediate test, shows little difference between the lists of high and low frequency. The amount forgotten during the 7-day period is significant ($F = 26.43$, $df = 1/60$, $P < .001$, following a Freeman-Tukey square-root transformation); neither Material nor the Retention Interval × Material interaction is significant. Thus, the change from a paced to an unpaced test results in approximately equal gains in the recall of the two kinds of materials. We conclude that the conditions of the anticipation test do not mask a greater availability of the high-frequency items.

Order of recall.—As Fig. 6 shows, there was a high degree of correspondence between the serial positions of the items in learning and the order of their appearance in free recall. The relationship is, however, less regular for the high-frequency lists than for the low-frequency lists. In order to obtain an index of serial order in free recall, the mean distance between the serial positions of successive items in recall was determined for each *S*. On the 30-sec. test, the mean index was 1.87 ($SD = .82$) for the high-frequency lists, and 1.38 ($SD = .76$) for the low-frequency lists. On the 7-day test, the corresponding means were 2.79 ($SD = .87$) and 2.23 ($SD = .89$). The rise in the index as a function of time is significant ($F = 18.80$, $df = 1/60$, $P < .001$) as is the difference between Materials ($F = 6.68$, $df = 1/60$, $.01 < P < .02$). The separation between the lists occurs on both tests and does not interact with the Retention Interval ($F < 1$). The greater disturbance of serial order in the recall of the high-frequency lists may be considered a function of unit-sequence interference and represents an effect on free recall which is parallel to the greater incidence of intralist errors on the anticipation test. These effects of unit-sequence interference appear to be present in

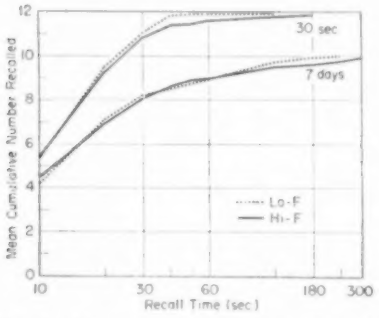

FIG. 5. Mean cumulative numbers of words reproduced in the 5-min. test of free recall.

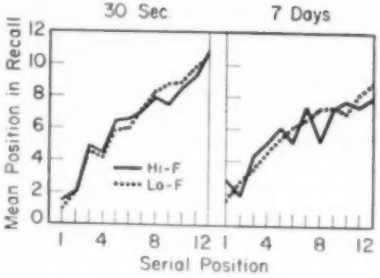

FIG. 6. Mean serial position of correct items in free recall as a function of serial position in learning.

considerable strength a very short time after attainment of the criterion.

Importations from outside the lists.—In contrast to the anticipation method, the 7-day test of free recall yielded an appreciable number of importations from outside the lists. During the recall of the high-frequency lists there were 14 importations contributed by eight *Ss*; during the recall of the low-frequency lists two *Ss* made a total of four such errors. The difference in the number of *Ss* giving importations is significant ($\chi^2 = 5.24$, $df = 1$, $.02 < P < .05$). There were no importations on the 30-sec. test, and their appearance on the delayed test may be attributed to extra-experimental interference. In agreement with this interpretation, the importations could be readily classified as synonyms or associates of the items in the list. The fact that free recall yields more importations than an anticipation test indicates that the reinstatement of the context of the list in relearning facilitates differentiation between correct and incorrect responses. A similar difference in the probability of importations as a function of the method of measurement was reported earlier by Postman and Rau (1957).

Experiment III

Method

Materials.—The learning materials were 12-word lists. Six of the words in each list were high-frequency items, and six words were low-frequency items. The same pool of words was used as in the first two experiments (Table 1). There were eight basic lists and four different serial orders for each of these, making a total of 32 different lists. The following rules were observed in the construction of the lists: (*a*) At each serial position, a high-frequency item was used in half the lists, and a low-frequency item was used in the other half of the lists. Thus, the effects of serial position were fully counterbalanced. (*b*) No item appeared more than once in any serial position. (*c*) No forward sequence of two items was used more than once. (*d*) No more than two items from the same frequency class appeared in succession. (*e*) There was no duplication of first letters in any of the lists.

Procedure.—The lists were presented on a Hull-type memory drum at a 2-sec. rate, with an intertrial interval of 6 sec., and learned by the anticipation method to a criterion of one perfect recitation. Retention was tested by relearning either after 30 sec. or after 7 days. Relearning was for five trials or to a criterion of one perfect recitation, whichever took the longer.

Subjects.—There were 32 *Ss* each in the 30-sec. and 7-day conditions. Since there were 32 lists, each *S* in a given condition learned a different list. The *Ss* were assigned to the conditions in blocks of two, one each in the 30-sec. and 7-day group. The running order within each block was determined by a table of random numbers, as was the assignment of lists to *Ss* within each condition. All *Ss* had English as their native language and were naive to rote-learning experiments. In view of the results of the earlier studies no *Ss* were replaced because of deliberate rehearsal. No *Ss* had to be rejected because of failure to learn.

Results

Original learning.—The mean number of trials to criterion for the 30-sec. and 7-day groups were 18.31 ($SD = 8.47$) and 17.81 ($SD = 6.09$). The difference in speed of learning is clearly not significant ($t = .27$), and the analysis of original learning will be presented for the combined groups.

The mean number of correct responses per trial was 3.46 for the high-frequency words and 3.29 for the low-frequency words. Although this difference in the rate of correct responses per trial was small, it was quite consistent and statistically significant ($t = 5.86$, $P < .001$). Analysis of the individual records shows that serial position was the primary determinant of the rate at which individual items were learned. Nevertheless, word-frequency produced a reliable effect in the expected direction when

TABLE 5

MEAN RECALL SCORES AND MEAN NUMBERS OF CORRECT ANTICIPATIONS ON RETENTION TESTS FOR MIXED LIST IN EXP. III

Retention Interval	Recall Scores				Anticipations in Relearning			
	High Frequency		Low Frequency		High Frequency		Low Frequency	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
30 Sec.	5.12	1.32	5.00	1.30	26.56	3.18	26.56	2.50
7 Days	2.91	1.77	2.16	1.66	22.28	5.20	20.97	6.00

serial positions were fully counterbalanced. It is apparent that the influence of word-frequency on learning is less within a mixed list than between homogeneous lists.

Errors during original learning.—The mean number of overt errors per trial was 1.26 (SD = .60). The mean percentage of intralist errors was 91.59. The intralist errors were, in turn, classified according to the frequency values of the item eliciting the error and of the incorrect response. These criteria yield a fourfold classification of errors—S_h-R_h, S_h-R_l, S_l-R_h, and S_l-R_l—where S and R stand for stimulus and response, and the subscripts designate the frequency class of each.[3] The frequencies with which each kind of error occurred were converted into percentages of opportunities. The number of opportunities was determined for each S by subtracting from the total number of presentations of a given class of stimuli the number of correct responses elicited by these stimuli. The mean percentages of the four types of errors were as follows: S_h-R_h—5.72, S_h-R_l—5.35, S_l-R_h—5.39, and S_l-R_l—4.81. There is a tendency for high-frequency responses to be given as errors more often than low-frequency ones, and for high-frequency stimuli to be more effective in eliciting errors. The differences among the percentages are, however, small and not significant. As was found for correct responses, the distribution of errors during learning was primarily a function of serial position. Whatever small differences are present are consistent with the view that response availability and probability of associative connection vary with frequency of usage.

Recall.—The mean numbers of the two kinds of items recalled are presented in Table 5. High-frequency words have a slight advantage on the 30-sec. test, and a more substantial one on the 7-day test. Analysis of variance (following a Freeman-Tukey square-root transformation) shows the retention loss during the 7-day interval to be highly significant ($F = 52.98$, $df = 1/62$, $P < .001$). The over-all effect of Material is also significant ($F = 6.74$, $df = 1/62$, $.02 < P < .05$), but the Retention Interval × Material interaction is not ($F = 3.43$, whereas a ratio of 4.00 is required for $P = .05$ with 1 and 62 df). The high-frequency items have a greater advantage than was found with homogeneous lists but there still is no reliable difference in the rate of forgetting for the two kinds of items.

Relearning.—Table 5 shows the mean number of high- and low-frequency words anticipated correctly

[3] Errors in the first serial position could not be included in this classification. Such errors were, however, extremely rare.

during the five relearning trials. The scores for the two kinds of items are closely similar. Thus, whatever advantage the high-frequency items had on the recall trial is quickly dissipated in the course of relearning.

Errors in recall and relearning.—A consideration of the overt errors in recall and relearning helps us to understand why the difference in the amount recalled remained so small even in a mixed list, i.e., in spite of the probable reduction in pre-experimental associations among the high-frequency items. As Table 6 shows, high-frequency responses occurred as errors more often than did low-frequency responses, and this difference increased as a function of the retention interval. Since there were very few errors of either class on the 30-sec. test, a nonparametric procedure was used to evaluate the significance of this trend. The *S*s in the two groups learning the same list were paired, and the proportions of cases in which there were increases in the two classes of errors were determined. Increases in high-frequency errors occurred in 53% of the cases whereas low-frequency errors increased in only 25% of the comparisons. The difference between the correlated proportions is significant ($CR = 2.54, P < .01$). Thus high-frequency responses recovered as errors more rapidly than did low-frequency responses. There were no comparable differences in the rate of recovery as a function of the frequency of the stimulus items. The results for the five relearning trials are fully consistent with those at recall. Having high meaningfulness in Noble's (1952) sense of the term, the high-frequency words entered readily into associations not only with other high-frequency words but with low-frequency words as well. As a result of differential recovery, there was again considerable competition among high-frequency responses at recall.

TABLE 6

NUMBER OF DIFFERENT CLASSES OF ERRORS IN RECALL AND FIVE TRIALS OF RELEARNING ON RETENTION TEST FOR MIXED LIST IN EXP. III

Class of Errors	Recall		Relearning	
	30 Sec.	7 Days	30 Sec.	7 Days
S_h-R_h	6	19	20	56
S_h-R_l	4	7	14	44
S_l-R_h	4	23	24	57
S_l-R_l	2	8	14	44
ΣR_h	10	42	44	113
ΣR_l	6	15	28	88

The assumption that response competition was more damaging to high-frequency items than to low-frequency items is supported by an additional analysis of the recall scores. In order to estimate the total number of *different* items recalled by each *S*, credit was given for anticipatory intralist errors as well as correctly placed responses. An item which occurred both as an anticipatory error and as a correct response was, of course, only counted once. The revised recall scores for the high-frequency items drop from 5.22 on the 30-sec. test to 3.19 on the 7-day test. The corresponding scores for the low-frequency items are 5.03 and 2.22. When some of the effects of unit-sequence interferences within the list are thus partialed out, high-frequency items have a distinct advantage and the Retention Interval × Material interaction is significant ($F = 5.49, df = 1/62, .02 < P < .05$). It may be noted that a similar analysis of the recall scores for the homogeneous list in Exp. I failed to produce an appreciable shift in favor of the high-frequency materials.

Discussion

To what extent do the experimental results support our conception of the conditions of extra-experimental interference? Turning to the findings on original learning first, we find in Exp. I and II that frequency of usage makes verbal units readily available as responses but at the same time favors a high rate of intralist errors. The differences between the high-frequency lists and the low-frequency lists with respect to the length of the integrative stage and the number and remoteness of overt errors provide significant evidence for the influence of pre-experimental habits on the course of acquisition. Since speed of learning and error rate are positively related, these findings do not demonstrate conclusively that pre-experimental habits are a source of interference in acquisition. The fact that the large difference between the lists during the integrative stage is not maintained during the associative stage makes it reasonable to assume, however, that the error rates reflect variations in the degree of associative interference. If this interpretation is correct, pre-experimental habits differentially retard the acquisition of the high-frequency lists. The results of Exp. III make it clear that our conclusions concerning the effects of frequency of usage on learning apply primarily to homogeneous lists. In a heterogeneous list the influence of frequency is largely masked by serial position effects. It is noteworthy, however, that whatever differences in the rate of correct responses and errors are present are consistent with those found with homogeneous lists.

The three experiments agree in failing to show a significant difference between the rates at which words of high and low frequency are forgotten. The hypothesis of unit-sequence interference would receive clear support if high-frequency items were forgotten faster than low-frequency items. This result was not found. On the other hand, the net advantage of the high-frequency materials in acquisition was not followed by comparable differences in retention. Thus, the persistent assumption that high meaningfulness necessarily favors retention can be rejected.

A larger number of overt errors is made in the recall and relearning of high-frequency items than of low-frequency items. The distributions of overt errors are consistent with the present analysis of the sources of extra-experimental interference. We assume that pre-experimental associations must be unlearned or extinguished during the acquisition of the prescribed list and that the rate at which such associations recover is a function of their initial strength. The fact that high-frequency responses appear as overt errors in recall and relearning more often than low-frequency responses bears out this expectation.

The results of the retention tests may be summarized by saying that there was no difference in the amount of forgetting for the two kinds of material in spite of the greater disturbance of serial order and the larger number of overt errors for the high-frequency items. Thus, the total pattern of responses in recall and relearning indicates that the greater initial availability of the high-frequency items is not followed by superior retention because of the rapid recovery of unit-sequence interferences. The argument in favor of our conception of extra-experimental sources of interference would, of course, be considerably more compelling if a significant difference in favor of the low-frequency lists had been found. It is possible that the rate at which pre-experimental associations recover is sufficiently slow to require longer retention intervals than those used in the present study for conclusive demonstration of differences in the amount of unit-sequence interference.

Summary

This paper reports three studies designed to explore the sources of extra-experimental interference in the forgetting of meaningful materials. In Exp. I, serial lists composed of either high-frequency words or low-frequency words were learned to a criterion of one perfect recitation, and retention was

tested by relearning after intervals of 30 sec., 2 days, and 7 days. In Exp. II, the same materials were used, and retention was tested by free recall after intervals of 30 sec. and 7 days. High-frequency words were learned faster than low-frequency words but neither method of testing showed a significant difference in the amount of forgetting. The number of overt errors was larger, however, during the recall of the high-frequency items. In Exp. III, mixed lists composed of equal proportions of high-frequency words and low-frequency words were learned to criterion, and retention was tested by relearning after 30 sec. and 7 days. Speed of learning for individual items was largely determined by serial position; the high-frequency items had, however, a small but consistent advantage. There was again no significant difference in the rate of forgetting for the two kinds of items. The theoretical analysis attributes forgetting to interference from extra-experimental associations established through linguistic usage.

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THE EFFECT OF DISCRIMINATION TRAINING ON EXTINCTION

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One method of training an operant discrimination calls for successive presentations in random order of a stimulus to which a response is reinforced (S_1^+), and another stimulus to which the response is nonreinforced (S_2^-). Under appropriate conditions, a high probability of response to S_1^+ and a much lower probability to S_2^- results. The main concern of the present experiment is to examine the effects of discrimination training of this type on resistance to extinction of the response to the previously reinforced stimulus.

There is a close relation between the events in discrimination learning and a simple intermittent schedule of reinforcement. If a response is first established to S_1^+, then early in discrimination training, presentations of S_2^- will also occasion the response (stimulus generalization). Since these responses go unreinforced, the pattern of reinforcement in a random series of S_1^+ and S_2^- presentations is intermittent. More specifically, reinforcement is intermittent with respect to responses, while it is perfectly correlated, or regular, with respect to the stimuli. Responses to S_2^- occur less frequently as discrimination training continues, and thus reinforcement becomes progressively more regular. The intermittency of reinforcement in discrimination training has been noted by others including Skinner (1938, p. 198), Wickens and Snide (1955), and Amsel (1958). Now, it is well established that intermittent reinforcement increases resistance to extinction over regular reinforcement. So, if it is assumed that intermittency of reinforcement in discrimination training has an effect similar to that of simple intermittency where only one stimulus is involved, then an increase in resistance to extinction would also be expected from discrimination training.

This expectation is, however, not supported by the results of experiments reported by Skinner (1938, pp. 197–201). He found that the extinction curve obtained following discrimination training resembled that obtained after regular reinforcement, not intermittent reinforcement. His observations suggested that even fewer responses were made after discrimination training than after regular reinforcement. The generality of his results may be questioned on two counts. First, the discriminations in these experiments were between grossly different stimuli (the presence vs. the absence of a light or click). Later discussion will indicate that the effect of discrimination training on resistance to extinction probably depends on the similarity of the stimuli to be discriminated. Second, the manner of presenting the discriminative stimulus was changed in the extinction phase of his experiments; a circumstance which might be expected to reduce the extinction curve.

A result more in line with expectation was obtained by Wickens and Snide (1955). They used a classical conditioning procedure and found that nonreinforced presentations of a component of the reinforced stimulus increased resistance to extinction. The authors state as an implication of their results that discrimination training increases resistance to extinction. However, the experiment gives only weak support for that conclusion since it appears that the conditioning procedure was not carried out long enough to produce a discrimination.

[1] The author wishes to express his appreciation to Edward Yontef, Herbert Terrace, and Charles Catania for their assistance in different phases of the research.

In the present experiment, extinction following discrimination training (DISC) was compared with extinction following two other training conditions involving only S_1 presentations. These conditions were: (*a*) training with regular reinforcement (REG), and (*b*) training with intermittent reinforcement (INT). Group REG received the same number of S_1^+ trials as did Group DISC. Group INT received both reinforced and nonreinforced S_1 presentations ($S_1^\pm$) in a sequence which closely matched the sequence of reinforcement and nonreinforcement that occurred in Group DISC. The three training conditions may be compared by noting that for Group INT, reinforcement is intermittent with respect to both the stimulus ($S_1^\pm$) and the response. In Group DISC reinforcement is regular with respect to stimuli (S_1^+, S_2^-), but intermittent with respect to responses as long as responses to S_2^- occur. In Group REG, reinforcement is regular with respect to both the stimulus (S_1^+) and the response. Comparisons among the groups will show whether discrimination training increases resistance to extinction over simple regular reinforcement, and if so, whether the intermittency of reinforcement in discrimination training is sufficient to account for the increase.

The experiment uses the pigeon's key-peck response. The procedure involves discrete trials (brief presentations of S_1 or S_2) separated by intertrial intervals. No more than one response may occur on a trial. By the use of this procedure, it is possible to control the sequence of reinforced and nonreinforced responses, as required by the design of the present experiment, if two conditions are met: (*a*) responses are largely confined to the trials, and (*b*) a high probability of a response on S_1 trials is maintained. The data consist of the occurrence or nonoccurrence of a response on a trial, and in the case of a response, its latency. Preformance during training as well as in extinction is analyzed in terms of both the occurrence and latency of responses.

Method

Subjects.—The *Ss* were male White Carneaux pigeons without prior experimental history. Body weight was maintained by restricted feeding at 80% of the weight under free-feeding. Complete data were obtained on 12 *Ss*, four in each of three groups.

Apparatus.—An automatic key-pecking apparatus (Ferster & Skinner, 1957, p. 14ff.) was used. The *S*'s compartment was 11 × 11 × 16 in. high. It was constantly illuminated by diffuse light from a source which extended across the top of the response panel. White noise was present continuously to mask sounds from the operation of the apparatus.

The reinforcement was a 3.5-sec. period of access to a tray of mixed grain. The operation of the tray was signaled by illuminating the opening to the tray. The part of the response key exposed to *S* was a circle of translucent plastic 1 in. in diameter. A raised metal collar around the key-opening prevented accidental operation of the key from a flap of the wings.

The stimuli were three straight parallel dark lines on the back-lighted key. The lines were 0.1 cm. thick and were separated by 0.2 cm. They were shown vertically for S_1, and horizontally for S_2.

A 20-pen Esterline-Angus Operations Recorder was used to record stimuli, responses, reinforcements, and response latencies. Latency was recorded in digital form to the nearest 0.1 sec.

Procedure.—The experimental sessions consisted of a series of automatically programed trials. A trial was initiated by the illumination of the key, showing either a vertical grid (S_1), or a horizontal grid (S_2). The stimulus was terminated (key-light turned off) by the first response to the stimulus, or by external control if no response was made within 5 sec. On reinforced trials, the tray operation followed a response immediately. During the interval between trials the key-light was off, but the compartment light remained on. The time interval between the onset of successive trials was

varied over four values: 15, 30, 45, or 60 sec. The frequencies with which intervals of these lengths occurred were (from shortest to longest) in the relation 8:4:2:1. The sequence of intervals was determined at random. Key-responses made during an intertrial interval prevented the onset of the next trial for 15 sec.

In preparation for the automatically programed sessions, *Ss* were trained to respond to S_1^+. The key-response was conditioned by reinforcing successive approximations. When 20 reinforced responses had been made to S_1^+, short intertrial intervals were introduced and gradually lengthened. The discrimination between a lighted and unlighted key formed almost immediately so that responses were largely confined to the trials from the beginning of training. Early trials were held beyond the 5-sec. interval where necessary. The procedure following the completion of preparatory training is summarized in Table 1. Other details were as follows. In Group DISC, S_1^+ and S_2^- were programed in random sequence subject to the restriction that the number of S_1^+ trials and the number of S_2^- trials in the first half of a session was equal to the number in the second half. Several different random sequences were used. The *Ss* in Group DISC were trained to the following criterion. Beginning with a session in which the probability of response to S_1^+ was equal to or greater than .9, while the probability of response to S_2^- was equal to or less than .1, 10 sessions were required for which the average probabilities of response to the stimuli were within these limits. Two *Ss* failed to reach this criterion after extended training and were replaced.

Each *S* in Group REG was matched to one *S* in Group DISC. Matched *Ss* received the same number of training sessions. Sessions for Group REG were programed by means of tapes that were also used for Group DISC, but the S_2^- trials were deleted by disconnecting the appropriate part of the circuit. One *S* in Group REG was replaced because it frequently made a second response immediately following the first response to the trial.

Also, each *S* in Group INT was matched to one *S* in Group DISC. Again, matched *Ss* received the same number of training sessions. Further, the sequence of reinforced and nonreinforced trials for *Ss* in Group INT was based on the performance of matched *Ss* in Group DISC. Each *S* in Group INT received 40 S_1^+ trials per session (same as in Group DISC) and in addition, received an S_1^- trial wherever the *S* to which it was matched in Group DISC responded to S_2^-. The matching was done on a trial by trial basis. This procedure resulted in closely comparable sequences of reinforced and nonreinforced responses for the two groups.

On Trial 1 of the first retraining session following the extinction series, responding

TABLE 1

SUMMARY OF PROCEDURE: STIMULI PRESENTED AND NUMBER OF SESSIONS IN EACH PHASE FOR THE DIFFERENT GROUPS
(Number of Stimulus Presentations per Session Shown in Parentheses)

Phase	Group			Number of Sessions
	Discrimination	Intermittent Reinforcement	Regular Reinforcement	
Pretraining	S_1^+ (40)	S_1^+ (40)	S_1^+ (40)	5 to 7
Training	S_1^+ (40) S_2^- (40 to 80)[a]	S_1^+ (40) S_1^- (varies)[b]	S_1^+ (40)	17 to 25
First Extinction	S_1^- (40) S_2^- (80)	S_1^- (40)	S_1^- (40)	10
Retraining	As in training	As in training	As in training	3
Second Extinction	As in first extinction	As in first extinction	As in first extinction	10

[a] Forty presentations of S_2^- in first two training sessions, 60 in next two, and 80 thereafter.
[b] Number of S_1^- presentations based on performance of discrimination group.

was re-established in the following way. The food tray was operated and *S* was permitted to eat for 4 sec. The S_1^+ was then presented and held, if necessary, until a response occurred. The procedure restored responding in every case. The interval between sessions generally ranged from one day to several days. However, in the extinction series the interval between sessions was either 2 or 3 days.

As a consequence of the experimental procedures, the three groups received the same number of sessions of the same duration; essentially the same total number of reinforcements; and essentially the same distribution of time intervals between reinforced trials. On the other hand, since trials were deleted from the program used for Group DISC in order to form the programs for Groups REG and INT, these latter groups received fewer trials per session, and so, on the average, waited a longer time between trials. The extinction phase in all groups was a continuation of training conditions except for the removal of reinforcement. Group DISC therefore continued to receive S_2 trials. The distribution of time intervals between S_1^- trials in extinction was the same in all groups. It should be noted that all three groups in this experiment formed a discrimination between the presence and absence of a trial, while only Group DISC received training to discriminate S_1^+ trials from S_2^- trials.

Results and Discussion

Performance during training met the conditions required by the experiment. First, a high probability of response to S_1 was maintained in each group. The over-all mean probability of response to S_1 was .985. Second, responses in the intertrial intervals were infrequent. One or more responses occurred in only 2% of the intertrial intervals. Third, the discrimination was learned to criterion by *S*s in Group DISC. The mean probability of response to S_2^- in Group DISC was only .051 over the last 10 sessions of training.

The plan of presentation of other results is to deal first with extinction, and then to examine performance in training for its bearing upon the interpretation of intermittency of reinforcement in discrimination learning.

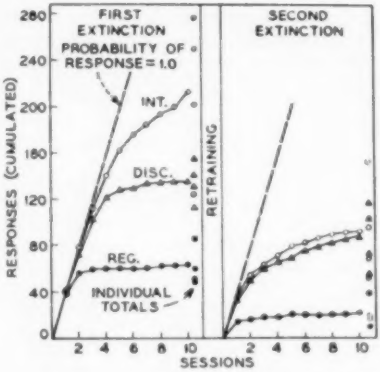

FIG. 1. Responses to S_1 in extinction for the different groups. Connected points show the mean number of responses cumulated over sessions.

Responses in extinction.—Responses to S_1 in the first and second extinction series are shown in Fig. 1. It may be recalled that Group DISC received both S_1 and S_2 trials in extinction. Responses to S_2 (not shown in Fig. 1) were relatively infrequent, averaging 15.8 for the first series and 9.5 for the second. An analysis of variance of the total responses to S_1 in the first extinction series showed the effect of the training condition to be significant ($F = 13.56$; 2/9 *df*, $P < .005$). Since the performance of matched pairs of *S*s did not appear to be related, the matching was disregarded in this and in subsequent statistical analyses. Regular reinforcement resulted in fewer extinction responses than did either discrimination training ($t = 6.15$; 6 *df*, $P < .001$) or intermittent reinforcement ($t = 4.38$; 6 *df*, $P < .01$). Although the mean difference between Groups INT and DISC was almost as large as that between Groups REG and DISC, it

failed to reach significance at the .05 level ($t = 2.25$; 6 *df*, $P < .10$) owing to the larger scatter of individual totals in Group INT. Extinction appeared to be more nearly complete for Group DISC in which no responses were made in the tenth session than in Group INT in which the four *Ss* made 1, 1, 14, and 37 responses.

Retraining after the first extinction series was begun by opening the food tray, which immediately reinstated responding to S_1. The over-all mean probability of response to S_1 for retraining sessions was .982. In Group DISC an increase in the probability of response to S_2^- over the level maintained in the last 10 sessions of training was observed. However, by the third session of retraining, the probability of response to S_2^- was less than .1 for each *S*.

In the second extinction series, each *S* made fewer responses than in the first. The total of responses in the second series was about half that of the first. The decline was the expected result of repeated conditioning and extinction (e.g., Bullock & Smith, 1953). The experimental groups again differed significantly in the mean number of responses in extinction ($F = 6.48$; 2/9 *df*, $P < .05$). Group REG, in which response totals for individual *Ss* remained below those for all other *Ss*, differed significantly from both Group DISC ($t = 4.31$; 6 *df*, $P < .01$) and Group INT ($t = 3.08$; 6 *df*, $P < .05$). Groups INT and DISC obviously did not differ significantly.

The results clearly show that discrimination training increased resistance to extinction over regular reinforcement. They further show that the pattern of intermittent reinforcement of response which occurs in discrimination training is capable, when applied to a single stimulus, of producing an increase in resistance to extinction over regular reinforcement as large or larger than the increase resulting from discrimination training itself. The second point implies that the increase in resistance to extinction is not directly related to the fact that S_1^+ is eventually discriminated from S_2^-. Rather, it is related to the occurrence of nonreinforced responses in the process of learning the discrimination. If the stimuli were very dissimilar so that after training on S_1^+, only a few responses were made to S_2^-, then a smaller increase in resistance to extinction would be expected to result from discrimination training.

Latency of response in extinction.—The latency of response to S_1 increased in extinction. In order to compare rates of increase in latency for the three groups in the face of large differences in the number of responses in extinction, mean latencies were computed for tenths of the total responses for each *S* and then averaged to give group mean curves. These Vincentized curves are shown for the first extinction series in Fig. 2. The increase in the mean latency during extinction was paralleled by an increase in the *SD* of the latency

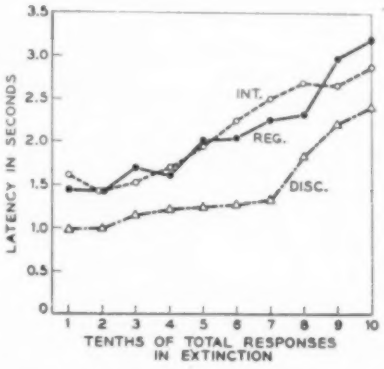

FIG. 2. Mean latency of response during the first extinction series for different groups.

distribution. The correlation of the mean with the *SD* of latencies over the 10 blocks of responses in extinction was computed for each *S*. The average correlation was +.82.

The over-all mean latencies for the three groups were significantly different ($F = 4.31$; $2/9$ *df*, $P < .05$). Group DISC differed from both Groups REG and INT ($P < .05$ by t test); Groups REG and INT did not differ significantly. In the second extinction series, there were no significant differences among the groups in mean latency, and the curves were like those for Groups INT or REG in Fig. 2. The similarity of the curves for Groups INT and REG is interesting. It means that even though Group INT made about three times as many responses as Group REG, the response latencies for comparable fractions of the total were similar. Of course, when latency is plotted against successive responses, rather than against equal fractions of the total, Group REG shows by far the highest rate of increase in latency. This is easily seen in terms of the curves in Fig. 2 when it is recalled that Group REG made many fewer responses than did the other groups. Some understanding of the fact that Group DISC maintained the shortest latency of response throughout the first extinction series comes from an analysis of performance during training.

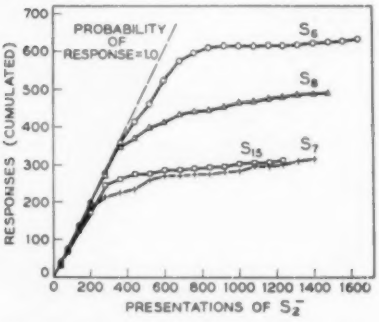

FIG. 3. Responses to S_2^- cumulated over sessions for individual *S*s in Group DISC.

Training.—Responses to S_2^- in the course of discrimination training are plotted cumulatively in Fig. 3. Responses to S_1^+ are not shown since the curves are indistinguishable from the slant line representing a response probability of 1.0. There was no indication of an immediate or spontaneous generalization decrement to S_2^- inasmuch as the probability of response to S_2^- remained at or close to 1.0 for two to six sessions in different *S*s.

The pattern of intermittent reinforcement generated in discrimination learning depends both on the proportion of S_2^- presentations and on the probability of response to S_2^-. The probability that a response was nonreinforced reached its highest level in the fifth session in which the number of S_2^- trials was increased to 80. At this stage of training, the group mean probability of response to S_2^- was .81, while the probability of response for the 40 S_1^+ trials was .99. This gave a mean probability that a response was nonreinforced of .62. During the last 10 sessions, the group mean probability of response to S_2^- was .05 which gave a mean probability that a response was nonreinforced of .09 for this segment of training.

When the reduction in probability of response to S_2^- occurred, it was accompanied by an increase in the latency of response to S_2^-. In order to represent the average course of latency changes in discrimination in the presence of large differences in the point at which *S*s first showed a reduction in the probability of response to S_2^-, the following procedure was used. The sessions for individual

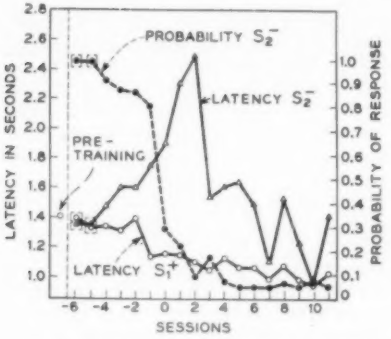

FIG. 4. Mean latency and probability of response during discrimination training. Mean latency for pretraining based on last three sessions. Training sessions for individual *Ss* have been shifted so as to line up on the first session in which the probability of response to S_2^- fell below 0.50 (Session 0). Points in brackets based on partial data.

Ss were renumbered, using zero for the first session in which the probability of response fell below .50, and counting forwards and backwards from that reference point. Average latencies were then obtained for these realigned sessions. The results are shown in Fig. 4 along with the group mean probability of response to S_2^-. Bracketed points are based on extrapolated values for one or two *Ss* and observed values for the other *Ss*. There was a sharp increase in the mean latency of response to S_2^- as the discrimination formed, and then a decrease as S_2^- responses became infrequent in the late stages of training. The downturn in the mean latency to S_2^- was evident in all *Ss* in Group DISC and is in some way due to concurrent reinforcement of responses to S_1^+. It will be recalled that in simple extinction, where all responses were nonreinforced, the mean latency continued to increase throughout extinction. Changes in the mean latency of response were closely paralleled by like changes in the *SD* of the distribution of latencies. For responses to S_2^- in Group DISC, the correlation of mean latency for a session with the *SD* for a session averaged +.90. For S_1 responses, where the range of variation was smaller, the correlation over *Ss* in all groups averaged +.60.

Group DISC showed a quickening of response to S_1^+ in the course of training which was not observed in the other groups. The change in latency resulting from training was found for individual *Ss* by taking the change in the mean latency from the last three sessions of pretraining to the last 10 sessions of training. In Group DISC there was a mean decrease in latency of 0.39 sec. ($t = 8.36$; 3 *df*, $P < .01$) while for Group INT there was a statistically insignificant mean increase of 0.19 sec., and for Group REG, essentially no change in the mean latency. The quickening of response to S_1^+ in Group DISC gave rise to significant differences among the groups in the mean latency of response during the last ten sessions of training ($F = 7.23$; 2/9 *df*, $P < .01$). The distributions

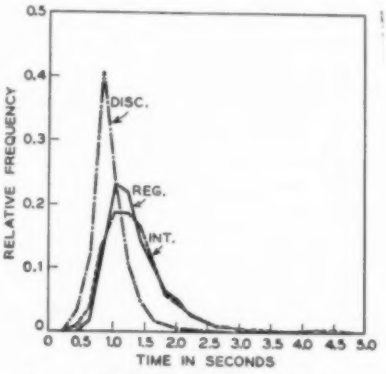

FIG. 5. Distributions of latencies (0.2-sec. intervals) over the last 10 training sessions for different groups. Distributions based on pooled data.

of response latencies to S_1 for the last 10 sessions of training are shown in Fig. 5. Comparisons of means by t tests showed that Group DISC differed from Groups INT and REG ($P < .01$ for each comparison), while the latter two groups were not significantly different.

The quickening of response to S_1^+ occurred only in Group DISC. Therefore, it cannot be explained as the effect of repeated reinforcement of S_1 responses since Group REG received the same treatment in this respect. Neither can it be explained as an effect of nonreinforced trials since these were received in the same number and sequence in Group INT. The conditions of training for Group DISC did differ from the others in that the average time between trials was shorter for Group DISC than for Groups INT or REG. (It may be recalled that the program tapes for Groups INT and REG were made up by deleting certain trials from the program for Group DISC.) However, an examination of the latency of response after different intertrial intervals failed to show an effect of the time since the preceding trial on the latency of response. Although this does not entirely discount the possible role of intertrial spacing

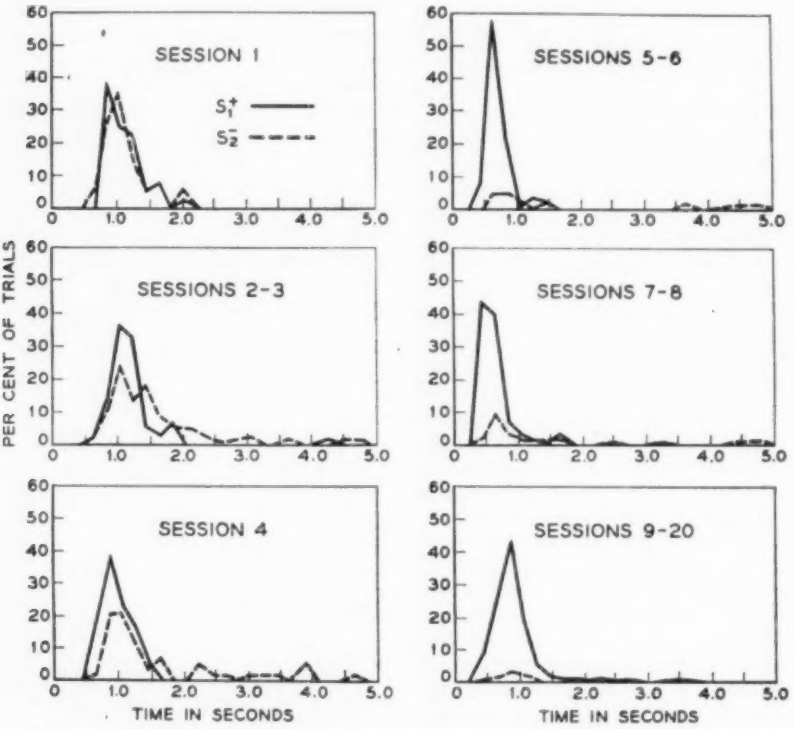

FIG. 6. Distributions of latencies (0.2-sec. intervals) for S_1^+ and S_2^- in discrimination training for one pigeon (S_7). Area under distributions proportional to probability of a response on a trial.

on latency, it does make it appear more likely that the explanation for the quickening in Group DISC lies in the discrimination learning process itself.

Relation between latency of response and probability of reinforcement in discrimination learning.—In Group DISC a special relation developed between the latency of response and the probability that a response was reinforced. This relation was one in which the probability of reinforcement was more favorable for responses of shorter latency. It may therefore help to account for the observed quickening of response. It arose in the following way. As the discrimination formed, the latency of response to S_2^- increased while the latency of response to S_1^+ remained, at first, relatively unchanged. This is shown in Fig. 6 which presents the latency distributions in the course of discrimination training for one bird (S_7). Data from consecutive sessions in which the distributions appeared to to be similar were pooled. The following features of the latency distributions in Fig. 6 were common to *Ss* in Group DISC: (*a*) the modal latency of response to S_2^- changed very little throughout the course of discrimination training; (*b*) as the probability of response to S_2^- decreased, the frequency of long latency responses to S_2^- increased; and (*c*) after the development of the "long tail" on the S_2^- distribution, there was a decrease in the mean latency of response to S_1^+ and the distribution of latencies became more peaked.

The predominance of long latency responses on the S_2^- trials (i.e., on nonreinforced trials) means that responses at shorter latencies had a higher probability of reinforcement. The relation of the latency of response to probability of reinforcement is shown for *Ss* in Group DISC in Fig. 7.

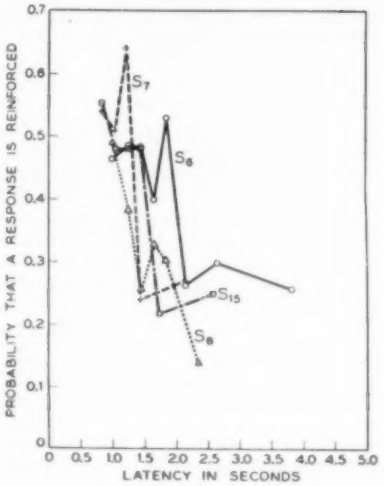

FIG. 7. Probability that a response is reinforced as a function of latency of response for individual *Ss* in Group DISC. Data from three sessions early in training.

In order to have a minimum of 20 observations for each of the points plotted in Fig. 7, adjacent 0.2-sec. intervals in the latency distribution were combined where necessary. The curve for each *S* is based on the three sessions numbered −4, −3, and −2 in Fig. 4. The first appreciable drop in latency of response to S_1^+ did not occur until the session numbered −1 in Fig. 4. Thus, the relation of probability of reinforcement to latency shown in Fig. 7 developed prior to the quickening of response to S_1^+. In Groups REG and INT there was no opportunity for a relation between latency and probability of reinforcement to develop. In Group REG, the probability of reinforcement was 1.0 for a response at any point within the 5-sec. period, while in Group INT it was statistically constant throughout the 5-sec. period. The average probability of reinforcement for the three sessions at the same point in training

as those used to obtain the functions plotted in Fig. 7 was .45.

These observations suggest the following account of the quickening of response to S_1^+ in discrimination training. The essential condition to get the process of quickening started is the development of frequent long latency responses to S_2^-. (No explanation for the increase in latency to S_2^- is here offered other than to note the qualitative resemblance to the increase in latency that occurs in simple extinction.) When this state of affairs arises, reinforcement becomes partially contingent on latency. This contingency selectively reinforces responses of short latency. The process is unstable; once started it gains momentum since an increase in the difference between the latency of reinforced and nonreinforced responses strengthens the contingency between reinforcement and latency and thus leads to a further difference in latency, and so on. The effect of the process is reduced as responses to S_2^- become less frequent. It should be noted that the contingency between response latency and reinforcement is spurious. There is in fact no such contingency on S_1^+ trials, nor on S_2^- trials, considered separately. The contingency appears only when the stimuli are disregarded and the data from S_1^+ and S_2^- trials are combined.

The present account of quickening depends critically upon the ability of selective reinforcement of quick responses to reduce latency. Skinner (1946) reported such a result. However, in his procedure the probability of reinforcement changed from one to zero at a cutoff point, whereas in the present case the probability fell off more gradually with increasing latency. However, the results on latency in extinction (Fig. 3) yield additional support for the contention that the discrimination procedure shaped responses toward shorter latencies. The DISC group entered extinction with the lowest mean latency of response and held nearly the same mean value over the first 70% of the total responses to extinction. An abrupt increase in the mean latency then appeared. It seems plausible that the differential reinforcement of quick responses would give this result. An analogous effect on the rate of response in extinction is produced by differential reinforcement of high rates during conditioning (Ferster & Skinner, 1957, pp. 495–497). In this connection, it is of interest to note that an increase in rate of response to the reinforced stimulus in discrimination training has been reported (Hanson, 1959; Smith & Hoy, 1954). The explanation here offered for quickening in terms of latency would also apply to a speedup in rate.

Whether or not the present interpretation of how discrimination training results in a quickening of response to S_1^+ proves correct, the fact remains that discrimination training resulted in a higher probability of reinforcement for responses of shorter latency. This result seems to provide a basis for a systematic difference in extinction following discrimination training when compared with intermittent reinforcement on a single stimulus. In terms of the micromolar behavior theory advanced by Logan (1956), responses differing sufficiently in latency are viewed as different responses. Moreover, it appeared from observations of *Ss* in the present experiment that the movement pattern for short latency responses was systematically different than for responses of relatively long latency. In discrimination then, the class of responses occurring on reinforced trials did not completely overlap the class occurring on nonreinforced trials. In effect, responses of the type that were reinforced received less nonreinforcement in Group DISC than in Group INT since in Group INT there was no systematic difference between the form of response on reinforced and nonreinforced trials. One would therefore expect less resistance to extinction following discrimination training than following a matched schedule of intermittent reinforcement with respect to a single stimulus. That is what was found in the first extinction series, although the difference fell short of statistical significance.

Summary

In order to identify an intermittent reinforcement effect in simple discrimination learning, resistance to extinction was compared following discrimination training, regular reinforcement, and intermittent reinforcement. The pattern of reinforcement for intermittent training was matched to the one produced by *Ss* in learning the discrimination. Data were obtained on 12 pigeons, four in each group. The experimental observations consisted of the occurrence or nonoccurrence of a key-peck response on a trial, and in the case of a response, its latency.

The results supported the view that an intermittent reinforcement effect is present in discrimination learning since (*a*) the mean number of responses in extinction following discrimination training was more than twice the number following regular reinforcement, and (*b*) extinction following intermittent training showed that the effect of the intermittent pattern of reinforcement generated in discrimination learning was sufficient to to produce the observed increase in resistance to extinction.

Discrimination training produced a quickening of response to the reinforced stimulus and a slowing of response to the nonreinforced stimulus. As a result, reinforcements became correlated with latency in discrimination learning, but not in simple intermittent reinforcement. This difference provides a basis for expecting less resistance to extinction where a discrimination is formed than where only one stimulus is presented and intermittently reinforced. The data gave some support to this expectation.

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TEST OF STIMULUS SAMPLING THEORY FOR A CONTINUUM OF RESPONSES WITH UNIMODAL NONCONTINGENT DETERMINATE REINFORCEMENT [1]

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In the last decade a large number of quantitative experimental studies of simple learning have been made for cases in which the reinforcement schedule is probabilistic and the number of possible responses is finite. Both stimulus sampling and linear models have been used extensively to analyze these studies. There have been, as far as we know, no previous attempts to extend these models to situations which permit a continuum of possible responses. Such is the aim of the present study, which may be briefly described as follows.

The S is told that his task on each trial is to predict by means of a pointer where a spot of light will appear on the circumference of a circle; S's responses are his pointer predictions. At the end of each trial the "correct" position of the spot is shown to S; this is the reinforcing event for the trial. The response x and the reinforcement y vary continuously along a circle from 0 to 2π. The most important variable controlled by E is choice of a particular probability distribution of reinforcement. In the present study reinforcement is noncontingent, i.e., the probability distribution of reinforcements is independent of S's responses and the same distribution is used on every trial. Moreover, the reinforcement is determinate because exactly one reinforcement y occurs on each trial. The purpose of a model is to predict the probability distribution of responses.

To analyze this situation we shall apply the stimulus sampling and linear models developed in Suppes (1959, 1960). Because the stimulus sampling model provides a more detailed account of the psychological process of learning than does the linear model, and because its mathematical development is somewhat simpler, we shall concentrate mainly on it. However, the theoretical results considered here also hold in the linear model.

Stimulus sampling model.—The basic theory derives from Estes (1950). Roughly speaking, this theory runs as follows. On each trial S samples a set of stimuli each of which is conditioned to exactly one response. The probability that S will make a given response is the proportion of sampled stimuli conditioned to that response, and all the sampled stimuli become conditioned to the response which is reinforced. Thus, theoretically the learning process is described in terms of the states of the conditioning of the stimuli, these states not being directly observable. For many experiments it has proved desirable to assume that exactly one stimulus is sampled on each trial and that the probability is not necessarily one that the sampled stimulus becomes conditioned to the reinforced response. We shall designate as θ the probability that reinforcement is *effective* and shall postulate the usual independence of path assumptions for this probability. In our context θ plays

[1] This research was supported by the Rockefeller Foundation and the Group Psychology Branch of the Office of Naval Research.

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the role of the learning parameter. To simplify considerably the mathematics we assume there is exactly one stimulus element that is available for sampling on every trial and is therefore sampled with probability 1.0. Most of the theoretical results given here actually do not depend on this one-element assumption.

For a continuum of responses, one fundamental modification in the theory just described seems called for. The assumption that each stimulus is conditioned to exactly one response seems unsound, and we replace it with the assumption (Suppes, 1960) that the conditioning of each stimulus is *smeared* over a certain interval of responses, possibly the whole continuum. We represent the conditioning of any stimulus by a *smearing distribution*, $K(x; y)$. It is postulated that parameter y, the mean of the distribution, takes on the value of the point of reinforcement when the stimulus is sampled and reinforcement is effective. In mathematical language, the basic learning process is a continuous-state discrete-trial Markov process in parameter y. On each trial, with probability θ, y moves to the new point of reinforcement, and with probability $1 - \theta$ it stays in the same place.

Various intuitive arguments can be given to support the representation of conditioning by a smearing distribution. It might seem that the best one would be based on well-known psychophysical facts about the impossibility of making exact discriminations among a continuum of choices. From this standpoint the smearing distribution would arise from the perceptual inability of the organism to distinguish exactly a given point on the continuum. However, the empirical estimates of the smearing distribution, which are discussed in detail later, yield a variance for the distribution which is far in excess of that which can be justified on purely psychophysical grounds. It seems likely that a better argument can be put together in terms of ideas of response generalization, but to make these ideas precise would require theoretical developments beyond the scope of the present paper.

We now summarize the results which are proved in Suppes (1960) and which we shall use in the analysis of data. In the form given, the equations hold only for a noncontingent reinforcement distribution, $F(y)$.[3] Let $[a, b]$ be the interval of possible responses; let $r_n(x)$ be the mean response density averaged over *Ss* on trial n; and let $k(x; y)$ be the smearing density of the single stimulus. Then we have the recursion

$$r_{n+1}(x) = (1 - \theta)r_n(x) + \theta \int_a^b k(x; y)f(y)dy \quad [1]$$

and thus for $r(x) = \lim_{n\to\infty} r_n(x)$, the important asymptotic relation

$$r(x) = \int_a^b k(x; y)f(y)dy \quad [2]$$

Multiplying both sides of Equation 1 by x^r, using Equation 2 and integrating with respect to x, we obtain as the recursion for the rth raw moment $\mu_{r,n}$ of $r_n(x)$

$$\mu_{r,n+1} = (1 - \theta)\mu_{r,n} + \theta\mu_r \quad [3]$$

and this difference equation may be solved explicitly to yield

$$\mu_{r,n} = \mu_r - [\mu_r - \mu_{r,1}](1 - \theta)^{n-1} \quad [4]$$

where $\mu_r = \lim_{n\to\infty} \mu_{r,n}$. Let $\mathcal{E}_n$ and σ_n^2 be the mean and variance of $r_n(x)$; and $\mathcal{E}$ and σ^2 the mean and variance of the asymptotic distribution $r(x)$. Then the recursion for σ_n^2 is as follows:

$$\sigma_{n+1}^2 = (1 - \theta)\sigma_n^2 + \theta\sigma^2 + \theta(1 - \theta)(\mathcal{E}_n - \mathcal{E})^2 \quad [5]$$

We use these last two equations to estimate θ. It is important to note that if the initial and asymptotic mean response densities are estimated directly from the data, then Equations 3–5 may be used independently of any particular choice of a smearing distribution $K(x; y)$.

Also independent of the choice of a smearing distribution is the prediction from Equation 2 that for a unimodal re-

[3] We use capital letters for distributions and lower case letters for the corresponding densities.

inforcement distribution the dispersion of the response distribution is greater than that of the reinforcement distribution. This particular prediction is an excellent gross test of the theory, for the rational strategy in terms of statistical decision theory is to make all responses at the mean of the reinforcement distribution and thus to have an asymptotic response distribution with zero variance.

It may also be shown that the variance of the asymptotic mean response distribution is approximately the variance of any long sequence of an individual *S*'s responses. This means that the prediction about the dispersion of responses is a prediction about individual behavior, not simply that of the group of *S*s.

In like fashion it follows from Equation 2 that if the reinforcement and smearing distributions are symmetric, then the response distribution is also symmetric. Again this is a prediction that should hold for individual *S*s as well as for group averages.

The method used for estimating the smearing distribution is discussed below.

Method

Subjects.—Twenty-three male and thirty-seven female Stanford undergraduates, obtained from the student employment bureau and through personal contact, were employed as *S*s. Each *S* was paid $1.25 for the 1-hr. experimental session.

Apparatus.—From *S*'s side the apparatus appeared as a vertical blue plastic screen 6-ft. square mounted 8 in. above the floor. At either side hung heavy white curtains which blocked *S*'s view of the area beyond the screen. A small amount of indirect illumination came from behind the curtains.

The translucent plastic was stretched across a 4-in.-deep wooden box. A $\frac{3}{8}$-in. steel shaft supported horizontally in a bearing mounted on the back of the box projected 21 in. on *S*'s side of the screen. Within the enclosure, light sources supported on a counterbalanced arm affixed to the shaft were arranged to project a $\frac{1}{4} \times \frac{3}{4}$-in. bar of red light onto the screen at either 1.25 ft. or 2.5 ft. from the shaft. Light sources were 6.3-v. pilot lights (RCA No. 47) covered by red plastic domes. The short dimension of the bars of light was perpendicular to the supporting arms.

By turning a knob on the end of the shaft *S* could make his prediction by positioning the light bar at any point on the 2.5-ft.-diameter circle about the axis of the shaft (or 5.0-ft.-diameter circle, depending on *S*'s group). The *S* was seated at a classroom desk chair so that the shaft was about at eye level. An optional arm rest was mounted on the chair arm and *S* was instructed to use either hand and to change hands or position whenever he wished.

A 23-in.-diameter scale with 400 equally spaced divisions was mounted behind the enclosure to indicate the location of the light. The entire scale could be rotated to change the physical location of the zero point. By turning a knob on his end of the shaft, *E* could position the light bar to indicate reinforcement location.

A 40-w. fluorescent light tube mounted over the scale furnished the only illumination in the experimental room.

Procedure.—After acquainting *S* with the method of operating the equipment, *E* read the following instructions.

> In various military situations the most effective operators of radar fire-control and target-locating devices are those who most frequently anticipate the approximate location of the next target. We are studying how this skill is developed.
>
> If you are holding the knob, please release it and I will show the target. Do you see the bar of red light that is moving around the screen? The target may be anywhere on the circle that the light is moving in. (Stop light at top of circle.) You will use the knob in front of you to move the light to where you think the target will be. Try it. O.K.? Now, when you have the light where you want it, release the knob and say, "Mark!" Then I will move the light to the target position and say, "Target!" As soon as you see where the target is take the knob again and move the light to where you think the next target will be, release the knob, and say, "Mark!" Then I will show you the target position as before. Because time is limited, you will only have 5 sec. to make your decision each time. You will seldom need this much time, but when you exceed the limit I will say, "Time!" and you will then have 1 sec. to position the light.
>
> At first, you will have to guess about the target location, but, with practice, your predictions should improve. The factors which determine target location are very complex, and you will find that target position changes quite erratically. You will seldom

be able to make an exact prediction but errors should reduce so that much of the time your predictions are close to the vicinity of the target.

As soon as questions had been answered by paraphrasing the instructions 300 trials were run without interruption. The average rate was 6 trials per minute.

Design.—There were two groups of 20 *Ss*, one group using the 2.5-ft. circle and the other the 5.0-ft. circle.

Thirty 300-trial reinforcement sequences were computed using the triangular density shown in Fig. 2 below. By random choice 30 equally spaced divisions of the circle, starting from arbitrary fixed physical zero, were assigned without repetition as scale zero points for the separate reinforcement sequences. Each reinforcement sequence was employed for one *S* using the 2.5-ft. circle and one *S* using the 5.0-ft. circle. The *Ss* were assigned to circle sizes randomly with the restriction that matched reinforcement sequences were run successively.

Results and Discussion

Response histogram variances over trials.—Table 1 shows the means and variances of the response histograms averaged over *Ss* in each group in blocks of 50 trials. The closeness of the means in the first block of trials to the mean, π, of the reinforcement distribution is due to the randomly selected scale origin for each *S*. The randomization of the physical position of the scale origin guarantees a uniform distribution on Trial 1 as the number of *Ss* becomes large, and the mean of the uniform distribution on the interval 0 to 2π is π. Consequently we have used the change in variance of the response histogram to estimate learning parameter θ.

The rates of decrease in the variances indicate both groups were close to their asymptotic variances at the end of the first 100 trials, if we take the variances of the last two blocks of trials as an estimate of the asymptotic variances. In Fig. 1 are plotted the variances of the response histograms averaged over *Ss* in each group in blocks of 10 trials for the initial 100 trials. Because of its small magnitude, the term $\theta(1-\theta)(\mathcal{E}_n - \mathcal{E})^2$ in Equation 5 was omitted, yielding the recursion

$$\sigma_{n+1}^2 = (1-\theta)\sigma_n^2 + \theta\sigma^2$$

which has the solution

$$\sigma_n^2 = \sigma^2 - (\sigma^2 - \sigma_1^2)(1-\theta)^{n-1}$$

Averaging over blocks of 10 trials, we have, for $i = 1, 2, \cdots, 10$

$$\sigma_i^2(\theta) = \frac{1}{10}\sum_{r=10i-9}^{10i}\sigma_r^2$$

$$= \sigma^2 - \frac{1-(1-\theta)^{10}}{10\theta} \times (\sigma^2-\sigma_1^2)(1-\theta)^{10(i-1)} \quad [6]$$

TABLE 1

Observed Means and Variances of Response Density for Blocks of 50 Trials

Block	2.5-Ft. Circle		5.0-Ft. Circle	
	Mean	Var.	Mean	Var.
1	.990	.258	1.037	.260
2	.991	.223	.998	.229
3	.991	.228	.998	.219
4	.996	.224	.990	.210
5	1.011	.225	.984	.215
6	.990	.219	1.001	.197

Note. All table entries are observed values divided by π for means and π^2 for variances.

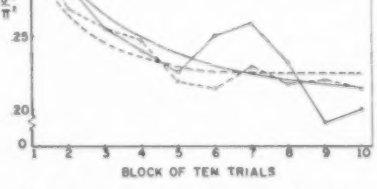

Fig. 1. Observed variances of $r_n(x)$ in blocks of 10 trials for initial 100 trials and variance curves fitted by least squares.

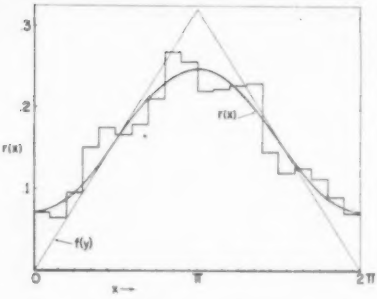

FIG. 2. Response histogram for 2.5-ft. circle and fitted response density for last 200 trials.

Equation 6 and the observed variances $\sigma_i^2(\text{obs})$ were used to find by the method of least squares the value of θ which yields a curve which best fits, for each circle, the observed variances plotted in Fig. 1. That is,

$$L(\theta) = \sum_{i=1}^{10} [\sigma_i^2(\text{obs}) - \sigma_i^2(\theta)]^2$$

was minimized. Because the derivative of $L(\theta)$ with respect to θ is a complicated function, the minimum was not found by analytical methods but $L(\theta)$ was computed for each circle and the minimum θ approximated to four decimal places. For the 2.5-ft. circle, the estimated θ is .0650, and for the 5.0-ft. circle the estimated θ is .0325. The fitted curves based on the estimated θ's are shown in Fig. 1. These computations were based on the assumption that $\sigma_1^2 = \frac{\pi^2}{3}$, the variance of the uniform distribution on the interval $[0, 2\pi]$. The fit to the data from the 2.5-ft. circle is the better of the two. This is because of the unexpected increase in variance following Block 5 for the 5.0-ft. circle. The increase is contrary to the theory and seems to be too large to be due to sampling error. The estimates of θ are surprisingly close to those obtained by Estes and Straughan (1954) from the mean learning curve for two-choice noncontingent data.

Asymptotic response histograms.—Figures 2 and 3 present for the two groups of *S*s response histograms in class intervals of $.1\pi$ for the last 200 trials. The triangular reinforcement density $f(y)$ is also shown in both figures.

The reinforcement density $f(y)$ has a mean of π and a variance of $.167\pi^2$. The response histogram for the group of *S*s using the 2.5-ft. circle has a mean of $.997\pi$ and a variance of $.224\pi^2$. The response histogram for the group using the 5.0-ft. circle has a mean of $.993\pi$ and a variance of $.210\pi^2$.

Individual data are presented in Table 2. The mean, variance, and third central moment are given for each individual histogram for the last 200 trials. These moments for the 200 reinforcements are also tabled. Note that for each pair of *S*s, one for the 2.5-ft. circle and one for the 5.0-ft. circle, the moments of only one reinforcement histogram are tabulated because the two members of the pair received exactly the same sequence of reinforcements.

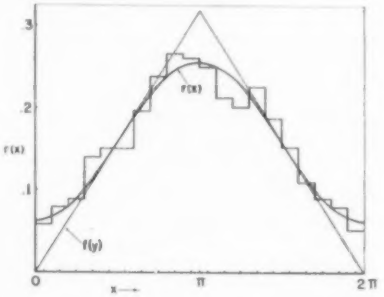

FIG. 3. Response histogram for 5.0-ft. circle and fitted response density for last 200 trials.

TABLE 2

INDIVIDUAL OBSERVED MEANS, VARIANCES, AND THIRD MOMENTS FOR LAST 200 TRIALS

S	Reinforcement Distribution			2.5-Ft. Circle			5.0-Ft. Circle		
	Mean	Var.	Third Moment	Mean	Var.	Third Moment	Mean	Var.	Third Moment
1	.95	.163	.000	1.01	.277	.006	1.00	.209	.003
2	1.03	.159	.002	1.03	.180	.000	.99	.253	.004
3	.98	.155	.002	1.08	.185	.007	1.02	.131	.005
4	.97	.173	.010	.97	.304	.016	1.03	.240	.004
5	.98	.164	.004	.96	.167	.000	1.07	.178	.011
6	1.04	.147	.000	1.01	.184	.013	.95	.128	.003
7	.98	.176	.005	1.10	.220	.001	1.10	.152	.015
8	1.03	.179	.002	.99	.149	.005	1.01	.197	.012
9	.97	.163	.000	.93	.240	.016	.96	.224	.001
10	.94	.170	.007	.97	.268	.031	.92	.221	.034
11	1.00	.156	.006	1.03	.305	.013	1.05	.210	.001
12	.98	.157	.001	1.04	.250	.019	1.01	.222	.005
13	1.00	.174	.008	.89	.138	.008	.97	.337	.021
14	.99	.175	.004	1.02	.202	.003	.96	.169	.002
15	1.01	.157	.003	.94	.160	.011	.91	.301	.006
16	1.01	.179	.002	.97	.209	.032	.92	.248	.020
17	.97	.181	.010	.96	.297	.003	.94	.256	.022
18	1.03	.214	.004	1.03	.228	.000	1.13	.262	.050
19	.95	.185	.009	.95	.225	.031	.86	.219	.040
20	.99	.152	.004	.94	.223	.009	.99	.146	.004
21	.97	.150	.006	1.02	.240	.006	.99	.188	.000
22	1.00	.166	.006	1.01	.172	.011	.96	.130	.006
23	1.01	.149	.007	.95	.204	.007	.97	.230	.007
24	1.01	.179	.002	.97	.203	.016	1.00	.291	.017
25	1.08	.149	.001	1.05	.168	.009	1.02	.089	.005
26	1.01	.171	.016	1.01	.291	.005	.99	.230	.001
27	1.02	.148	.008	1.08	.231	.017	.99	.170	.010
28	1.00	.169	.000	.95	.381	.018	1.04	.270	.003
29	1.00	.127	.006	1.00	.256	.002	1.01	.177	.003
30	1.02	.159	.003	1.09	.083	.004	1.04	.136	.012

Note. All table entries are observed values divided by π for means, π^2 for variances, and π^3 for third central moments.

Putting aside for the moment detailed quantitative questions, these individual data qualitatively support the fundamental theory in three important respects.

First, the means of the individual histograms are all quite close to the mean of the reinforcement distribution, as is predicted by the theory. In the case of the 2.5-ft. circle, only 3 *S*s deviate from the theoretical mean of 1.0π by more than does the most deviant reinforcement histogram (that for *S* 25). In the case of the 5.0-ft. circle there are only 5 such *S*s. The deviation from the theoretical mean of no *S* in either group is more than twice that of this most deviant reinforcement histogram (whose deviation is 15°). These results would seem to show that the reinforcement conditions obtaining in the experiment easily dominated any a priori positioning habits.

Secondly, the variances of the individual histograms are generally larger than those of the corresponding reinforcement histograms. In particular, this is true for 27 of the 30 *S*s on the 2.5-ft. circle and 22 of the 30 *S*s on the 5.0-ft. circle. This result shows rather clearly that there was no general tendency for individual *S*s to adopt the rational strategy of statistical decision theory,

i.e., asymptotically to respond very close to the mean of the reinforcement distribution.

Thirdly, the relatively small magnitudes of the individual third central moments indicate a high degree of symmetry in the individual histograms. The third moments for 21 *Ss* on the 2.5-ft. circle and 23 on the 5.0-ft. circle are larger than those of the corresponding reinforcement histograms, but none seems excessive; only 3 of the 60 *Ss* have a third moment more than twice the largest third moment of the 30 reinforcement histograms.

It seems to us that these results for individual *Ss* are sufficiently encouraging to warrant quantitative investigations of the extent to which individual *Ss* are satisfying the model. Such investigations will require many more trials than were obtained in the present study. For this reason the remainder of the analysis in this paper is restricted to group data.

Estimation of smearing distributions.—The noncontingent triangular reinforcement distribution shown in Fig. 2 and 3 is analytically defined by the density

$$f(y) = \begin{cases} \dfrac{y}{\pi^2} & 0 < y \leq \pi \\ \dfrac{1}{\pi^2}(2\pi - y) & \pi < y \leq 2\pi \end{cases} \qquad [7]$$

For the circular display it is reasonable to assume that the smearing distribution about a point of reinforcement, y, is symmetric, and therefore $k(x; y) = k(t)$, where $t = x - y$. For detailed analysis of data we restrict ourselves to two general forms for the smearing distribution—*uniform* distributions and *symmetric beta* distributions, with the free parameter of the distribution to be estimated from the data by use of Equation 2. Two things have motivated this choice, namely, the mathematical simplicity of both distributions and the fact that as m increases the symmetric beta distribution closely resembles the normal distribution, and thus has the bell shape which seems intuitively appropriate for a smearing phenomenon.

The *uniform smearing* density with parameter a is defined by

$$k(t) = \begin{cases} \dfrac{1}{2a} & |t| \leq a \\ 0 & a < |t| \leq \pi \end{cases} \qquad [8]$$

where $-\pi \leq t \leq \pi$ and $0 < a < \dfrac{\pi}{2}$. Combining Equations 2, 7, and 8, and integrating, we have for the asymptotic response density:

$$r(x) = \begin{cases} \dfrac{1}{2a\pi^2}(a^2 + x^2) & 0 < x \leq a \\ \dfrac{x}{\pi^2} & a < x \leq \pi - a \\ \dfrac{1}{2a\pi^2}(2a\pi - a^2 - (x - \pi)^2) & \pi - a < x \leq \pi \end{cases} \qquad [9]$$

for $0 < x \leq \pi$, and because $r(x)$ is symmetric about π, it is sufficient to know its values for $0 < x \leq \pi$. For estimation of a, it is desirable to compute the variance of $r(x)$ as defined by Equation 9, which is:

$$\sigma_{U(a)}^2(r(x)) = \frac{\pi^2}{6}\left[1 + \left(\frac{a}{\pi}\right)^2\left(2 - \frac{a}{\pi}\right)\right] \qquad [10]$$

where the subscript $U(a)$ denotes the uniform smearing distribution with parameter a.

The *symmetric beta smearing* density with parameter m is defined by:

$$k(t) = \frac{1}{\pi B(m, \frac{1}{2})}\left(1 - \frac{t^2}{\pi^2}\right)^{m-1} \qquad [11]$$

for $-\pi < t < \pi$ and $B(m, \frac{1}{2})$ the usual beta coefficient. (Because of the form of the reinforcement density $f(y)$, Equation 2 must be written as

$$r(x) = \frac{1}{\pi^2}\left\{\int_{-\pi}^{x-\pi} k(t)(2\pi - x + t)dt + \int_{x-\pi}^{x} k(t)(x - t)dt + \int_{x}^{\pi} k(t)(t - x)dt\right\} \qquad [12]$$

and thus in considering the beta smearing density it is necessary to restrict the exponent $m - 1$ to integer values in order to integrate Equation 11, which restriction turns out not to be serious.) Combining now Equations 2, 7, and 11, and again integrating, we obtain for $0 < x < \pi$:

$$r(x) = \frac{1}{\pi}\left\{\frac{(\pi^2 - x^2)^m - (\pi^2 - (x - \pi)^2)^m}{m\pi^{2m}B(m, \frac{1}{2})} + 1 - \frac{x}{\pi} + \frac{2}{B(m, \frac{1}{2})}\sum_{\nu=0}^{m-1}\binom{m-1}{\nu}(-1)^{\nu}\frac{x^{2\nu+2} - (x - \pi)^{2\nu+2}}{(2\nu + 1)\pi^{2\nu+1}}\right\} \qquad [13]$$

For the variance of $r(x)$ as defined by Equation 13, we have:

$$\sigma_{B(m)}{}^2(r(x)) = \pi^2\left\{\frac{2}{2m + 1} + \frac{3}{2(2m + 3)(2m + 1)} - \frac{2}{B(m, \frac{1}{2})}\left[\frac{1}{m(m + 1)} - 2\sum_{\nu=0}^{m-1}\binom{m-1}{\nu}(-1)^{\nu}\frac{B(2\nu + 3, 3)}{2\nu + 1}\right]\right\} \qquad [14]$$

Asymptotic response densities, as given by Equation 9 for the uniform smearing density and Equation 13 for the beta smearing density, were fitted by the method of moments to the response histograms shown in Fig. 2 and 3. In the present situation this amounted to estimating the values of parameters a and m, respectively, which determine asymptotic response densities whose variances (Equations 10 and 14) are equal to the variances of the histograms. The variances of the response histograms were computed from the individual observations and not from the frequency functions for the class intervals. The histograms and the fitted response densities both show the smoothing and spreading effects which are to be expected if the notion is correct of a distribution which smears the conditioning of the sampled stimulus.

As already stated, the response histogram for the group of *Ss* using the 2.5-ft. circle has a mean of $.997\pi$ and a variance of $.224\pi^2$. In order to fit this response histogram, if we take a uniform smearing density with $a = .475\pi$, we obtain an asymptotic response density with mean of π and variance of $.224\pi^2$. And if we take $m = 6$, we obtain for the beta smearing density, an asymptotic response density with mean of π and variance of $.222\pi^2$. The two response densities resulting from the two smearing densities are so nearly identical, it was possible to plot only one response density in Fig. 2; the one selected is that arising from

the beta smearing density. For numerical comparison, the maximum difference between the two response densities occurs at $x = 0$, for which $r_U(x) = .076$ and $r_\beta(x) = .071$. Goodness of fit tests for the response densities are given below.

The response histogram for the 5.0-ft. circle has a mean of $.993\pi$ and a variance of $.210\pi^2$. In order to fit this histogram, if we take a uniform smearing density with $a = .405\pi$, we obtain an asymptotic response density with mean of π and variance of $.210\pi^2$. And if we take a beta smearing distribution with $m = 8$, we get an asymptotic smearing density with mean of π and variance of $.211\pi^2$. Again the two response densities are so similar it was possible to plot only $r_\beta(x)$ in Fig. 3. At $x = 0$, $r_U(x) = .064$ and $r_\beta(x) = .063$.

Because of its greater circumference the larger circle permits finer discrimination; thus, when measurements are made in radians, the variance of the response density and that of the corresponding smearing density are less for the larger of the two circles. The four fitted smearing densities are plotted in Fig. 4.

Figure 5 presents the theoretical variance of the asymptotic response density as a function of parameter a of the uniform smearing density and also as a function of parameter m of the beta smearing distribution. The empirical variances of the response histograms for the two circles appear as horizontal lines in the figure. The figure shows that the use of integer values for parameter m of the beta smearing density is sufficiently sensitive for good estimation of the asymptotic response density. It should be noted that when the variance of the smearing distribution goes to zero, the asymptotic response density is identical with the noncontingent reinforcement density.

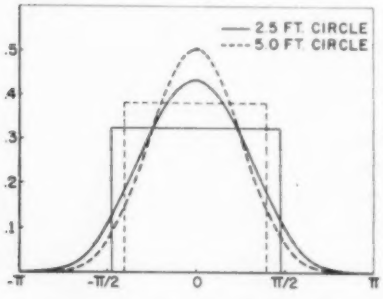

FIG. 4. Fitted smearing densities.

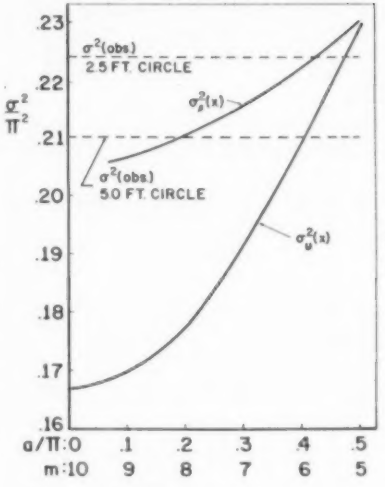

FIG. 5. Theoretical variance of $r(x)$ for uniform smearing density with parameter a and beta smearing density with parameter m.

Prior to detailed calculations it was not anticipated that the exact form of the smearing distribution would affect so slightly the form of the asymptotic response distribution. This is a highly encouraging result for the investigation of more complicated reinforcement distributions which pose increasingly difficult mathematical problems, for in most cases the possibility of assuming a uniform smearing distribution leads to considerable formal simplifications.

On the other hand, the near identity of the response distributions arising from the two different smearing distributions implies that there is little possibility of identifying from response histograms the general form of the smearing distribution. Theoretically Equation 2 may be regarded as an integral equation, and when $k(x; y)$ is taken to be symmetric, Equation 2 may be easily transformed into a standard integral equation of Fredholm type with the reinforcement density $f(y)$ as the kernel. Given $f(y)$ and an analytical function $r(x)$ it is then possible to determine the class of functions $k(x; y)$ which satisfy the integral equation. However, as the discussion of Fig. 1 and 2 has indicated, response densities of quite different analytical form fit the empirical response histograms equally well and the choice between them is empirically arbitrary. It remains to be seen whether other properties of the model, which have not been considered here, will yield a practical method for identifying the form of the smearing distribution.

Goodness of fit of response densities. —Inspection of Fig. 2 and 3 suggests that the response densities fit the response histograms better than the triangular reinforcement distribution does, and that the over-all fit is reasonably good. Because of the importance of this goodness of fit for evaluating the validity of the theory, it is pertinent to examine it more closely. The obvious procedure is to apply a χ^2 test, but the difficulty is that the 6,000 observations on which each histogram and fitted response density are based are not statistically independent, as is required for a χ^2 test. However, it is known that for stationary stochastic processes observations sufficiently spaced in trials are statistically independent. Following this line of thought, we considered responses on every fifth trial for each *S* starting with Trial 102. To test the statistical independence of these responses, we divided the circumference of the circle into six class intervals with approximately equal relative frequencies for the 2.5-ft. circle data. In terms of these six class intervals we then tested the null hypothesis that the 1200 responses were drawn from a zero-order Markov process (i.e., are statistically independent) against the alternative hypothesis that they were drawn from a first order Markov process. The appropriate χ^2 test is given in Anderson and Goodman (1957) and has been used repeatedly on learning data by Suppes and Atkinson (1960). For the 2.5-ft. circle, $\chi^2 = 32.97$, which with $(6 - 1)^2 = 25$ *df* has a significance level of $P = .20$. For the 5.0-ft. circle $\chi^2 = 30.66$, which with the same number of *df* has $P = .24$. For purpose of comparison the same test was run on the reinforcements occurring on the immediately preceding trial, i.e., Trials 101, 106, etc. Here $\chi^2 = 24.95$ which has $P = .49$. With 1,200 observations the power of this χ^2 test is high, so that with the obtained significance levels it is reasonable to accept the null hypothesis that the responses are statistically independent.

Using then the 1,200 statistically independent responses on each circle, the following results were obtained. First, the null hypothesis that the response data fit the reinforcement distribution was tested. On the basis of dividing the circle into 30 class intervals of approximately equal frequency for the 2.5-ft. circle data, the rejection of the null hypothesis was decisive. For the 2.5-ft. circle $\chi^2 = 154.21$ with 29 *df*, and for the 5.0-ft. circle $\chi^2 = 74.02$ with 29 *df*; both results are highly significant. In this instance, an aspect of the continuum theory is confirmed in which it differs from the discrete response theory. Numerous two-choice experiments have confirmed the matching

law that asymptotically the number of A_1 responses in any large block of trials is essentially equal to the number of E_1 reinforcements. Because of the smearing distribution in the continuum case, no such matching of response and reinforcement distributions is predicted, nor was it obtained.

Secondly, we tested for each circle the null hypothesis that the response distributions (Equation 9) with the estimated parameter a fit the response data. For the 2.5-ft. circle $\chi^2 = 47.56$ with 28 df, for which $P = .02$. For the 5.0-ft. circle $\chi^2 = 30.09$, also with 28 df for which $P > .30$. The somewhat disappointing result for the 2.5-ft. circle is entirely due to one cell which has an observed frequency of 66, whereas a frequency of 40.68 is predicted. The contribution of this one cell of the 30 to the χ^2 total is 16.15. Examination of the data for individual *Ss* indicates that this large figure cannot really be explained by unusual behavior of one or two *Ss*. The maximum contribution to the 66 total of any one S is 9. The fit of the remaining 29 cells is quite good, and, of course, the fit of the data from the 5.0-ft. circle is very satisfactory. The encouraging character of these results suggests a deeper analysis of sequential data in subsequent experiments; unfortunately, analytical computation of detailed sequential statistics is rather forbidding, although possible.

Summary

The study tests a formulation of stimulus sampling theory for a continuum of responses when reinforcement is determinate and the probability distribution of reinforcements is noncontingent, unimodal, and symmetric.

Sixty college students were run for 300 trials on a circular display apparatus. The *Ss*' responses consisted of predicting the location of a spot of light on the circumference of a circle. At the end of each trial S was shown the "correct" location, which constituted the reinforcing event for that trial. The *Ss* were divided into two groups, one of which used a circle with a diameter of 2.5 ft. and the other a circle with a diameter of 5.0 ft. The means, variances and third central moments of the last 200 responses for individual *Ss* were tabulated. The results are in good qualitative agreement with the theory. In particular, the means matched closely that of the reinforcement distributions, but the variances were generally larger, as predicted by the theory, in contrast to the zero variance of the rational strategy of statistical decision theory.

The learning parameter θ and the smearing distribution which represents the conditioning of the single stimulus were estimated from the data. Asymptotic response densities were computed by use of the estimated smearing distributions and were found to be highly similar for both assumed forms of the smearing distribution and to agree well with the observed histograms for both groups.

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EFFECTS OF ASPIRATION AND ACHIEVEMENT ON MUSCULAR TENSIONS

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In level of aspiration studies the response variable most commonly observed has been the quantifiable discrepancy between aspiration and achievement scores (D score), but there has been little if any attempt made to relate aspiration to physiological processes. Other areas of experimental investigation have demonstrated relationships between mental and emotional processes and muscular tension. Changes in muscular tension have been shown to affect the efficiency of mental work, and have been observed as an effect of variations in imagery, set, instruction, task difficulty, and success and failure (Bills, 1927; Courts, 1942; Davis, 1938). The sensitivity of the muscular tension response to varied psychological influences and its susceptibility to measurement in terms of muscle action potentials (MAP) suggests its usefulness in theory construction and its usefulness, in particular, as a response variable for level of aspiration experimentation.

The question this investigation attempts to answer is whether aspiration stated in realistic (expectant) terms exerts an influence upon muscle tension levels that is different from irrealistically (hopefully) expressed aspirations, and whether such influence has a functional relationship with achievement reported to *S* as either success or failure. Following Festinger's (1939) finding that an interaction obtains between the realism of aspiration and success and failure, it was predicted that different levels of muscular tension would result from the combined effects of realistic or irrealistic aspirations and success and failure.

Method

Forty-eight college undergraduates, 25 men and 23 women, were assigned at random to four groups of 12 *S*s each, designated on the basis of experimental treatment as Expect-Success, Hope-Success, Expect-Failure, and Hope-Failure. They were given a series of three tasks, equivalent in difficulty, involving the mental solution of sets of figure-pattern problems for which fictitious scores and norms were established as a means of reporting and controlling relative achievement. Following each task and a report to *S* of an achievement score, an expression of aspiration was elicited for the succeeding task. "Expect" groups stated aspirations in terms of scores they expected to obtain; "Hope" groups stated the scores they hoped or would like to achieve. Half of each group received a score which according to the norms indicated success, and the other half received a score indicating failure. Timed rest periods were interspersed between phases of the experimental treatment, which consisted, in sequence, of a criterion rest period to establish equivalent tension levels for the total sample; work on an initial practice task and a report of achievement in which all *S*s received the same score; *S*'s statement of aspiration in either realistic or irrealistic terms; work on Task I; a report of success or failure; a second statement of aspiration in the same terms as the first; and work on Task II, the final task.

The response observed was muscle action potentials (MAP) from *S*'s forearm muscles, taken during physical relaxation which he maintained throughout experimental treatment. Two *E*s were used: E_1 operated the recording apparatus consisting of a motion picture camera which recorded action poten-

[1] The author wishes to express his appreciation to William A. Shaw of the University of Pennsylvania for his guidance in the development and reporting of this experiment.

tials amplified and impressed upon an oscillograph screen; E_2 administered instructions and the tasks to each *S*, who was seated in a reclining chair in an electrostatically shielded cage with electrodes affixed to his right biceps and forearm muscles. The electrodes were coupled to the amplifier in the adjacent recording room where E_1 calibrated the equipment and coordinated recording with each phase of the experimental sequence. Photographic samples of MAP were taken at specified intervals during rest periods, initially and following statements of aspiration and reports of achievement, and during work on the tasks. The experimental data were measurements of the largest peak-to-peak deflections of MAP recorded on the photographic film.

Results

No statistically significant differences among the experimental groups appeared until *S*s became engaged in Task II, the final work period. It was observed, however, that the tension levels of all groups following the first statement of aspiration were significantly higher than during criterion rest, suggesting that expressing aspiration reliably increases muscular activity. Noted also was a trend of difference which carried into work on Task I, in which tensions of the hopeful *S*s were higher than those of the expectant group, suggesting some tendency for greater muscular responsiveness in the irrealistic *S*s (see Fig. 1).

When achievement (Success or Failure) was reported for Task I, a tendency for a greater amount of tension increase over criterion rest level was noted in the Failure than in the Success groups, and more variability appeared in the distribution of Hope-Failure responses than in the other three groups; no significant difference between group means was obtained, however.

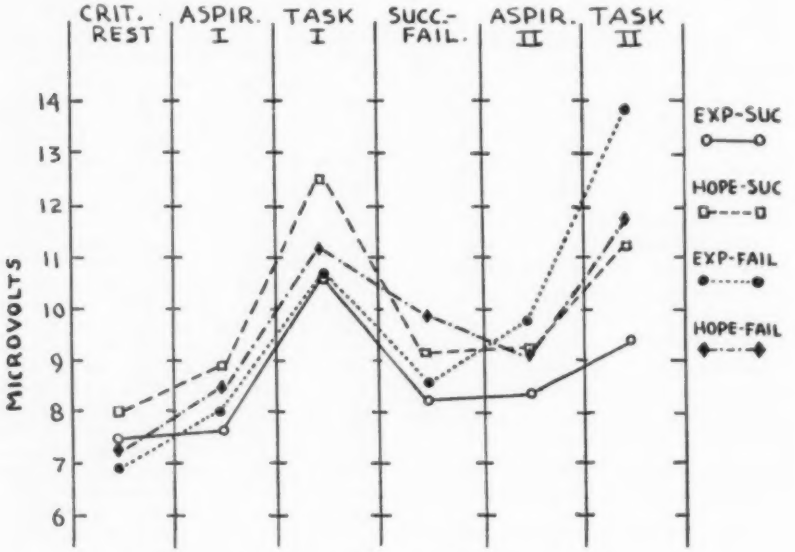

Fig. 1. Muscular tension responses of experimental groups through sequence of treatments.

During rest following the second statement of aspiration, the previously observed trend reversed, with the highest tensions appearing in the Expect-Failure group as well as the greatest variability of response, suggesting that this group may have been influenced more than the others by the combined effects of failure and the expression of realistic aspiration. The second highest tension levels were noted in the Hope-Failure *Ss*. In the Success groups, on the other hand, the irrealistic *S*'s tensions were higher than those of the realistic *Ss*.

In Task II, the final work period, the mean tension levels of both Success groups showed a decrement from Task I levels, while those of both Failure groups increased, indicating that an effect of failure was to stimulate greater effort and that success resulted in less effort. Tensions of the Expect-Failure *Ss* significantly exceeded those of the Hope-Failure and both Success groups. The Hope-Success *Ss* continued to show higher tensions than the Expect-Success group. That these effects were not a function of achievement alone was revealed by analysis of variance which yielded an F ratio of 6.86 ($.01 < P < .02$) for the interaction of Aspiration and Achievement. The F ratio of 11.75 ($P < .01$) was obtained for the Success-Failure source of variance.

The results suggest that whatever influences are exerted by a report of success or failure may not appear until *S* is engaged in work. During performance of the task, his tensions increase if he has been failing and decrease if he has been succeeding. A realistic aspiration in combination with failure appears to produce a stronger effect in elevating muscular tensions than either variable alone. On the other hand, when *S* succeeds, an irrealistic aspiration induces higher tensions than an expectant aspiration.

Discussion

The results of this study tend to support the hypothesis that variations in response to aspiration and achievement instruction are accompanied by and incorporate muscular reaction. Setting a goal seems to induce a significant increase in muscular tension during the waiting period preceding the task, suggesting that increased energy is discharged as *S* sets himself, or prepares himself, for the task. While this finding is inconclusive, since no control group was used, and may be a function of other variables, it tends to support the conclusions of Davis (1940) and Freeman (1939) on the relation of muscular tension to anticipatory reactions. Freeman offers a definition of set in terms of postural responses and central nervous function; Davis thinks of set as a pattern of incipient muscular and glandular activity. If these concepts are accepted, an aspiration for an ensuing task, the set toward a goal, may be considered as incorporating muscular reaction as a component aspect.

The findings suggest that hopeful aspirations are accompanied by greater muscular activity than expectations. It might be speculated that such a tendency should appear on the grounds that hopeful *Ss* set higher goals for themselves and are therefore set for greater exertion of effort, which would induce higher tensions. Further, a higher level of achievement may represent a more difficult task, which would account for higher tensions in accordance with observations of Davis (1938), Reuder (1950), and Shaw (1940) that muscle tensions increase with increasing task difficulty. Another consideration is that in setting goals hopefully, the individual is influenced by affective factors and may be more ego involved with the goal situation. As Reuder was able to show, ego-orienting instructions produce higher tensions than task-

orienting instructions when task difficulty is taken into account.

The different effects of success and failure, while in general agreement with the observations of other investigators (Clites, 1936; Davis, 1938; Klein, 1951), were found to be reliable only during work on the subsequent task and not during the rest period following the report. It is possible that a significant difference might have appeared if the rest interval were extended, in the form of temporal trends as in Klein's study, but this possibility was not investigated.

Confirmation of the hypothesis was obtained in the significant interaction effect during Task II. Festinger (1942, p. 198) had contended that, "While the realistic person cannot avoid the feeling of failure, the more wishful person can do so to a certain extent and therefore not respond to a failure situation." This contention is supported by the finding that the tensions of the Hope-Failure group were significantly lower than those of the Expect-Failure group during Task II.

Successful individuals apparently work less hard on the final task than failures. In the Success groups, the influence of aspiration combined with achievement resulted in higher tensions of the Hopeful *Ss*. It seems reasonable to assume that the irrealistic attitude would be reflected in Task II by successful *Ss* on the same ground that applies for the irrealistic failures; the latter *Ss* tend to set a maximum goal level and may be actually prepared *not* to meet it. Not only is the goal irrealistic but the failure also is irrealistic and *S* may be therefore less responsive to it (Lewin, Dembo, Festinger, & Sears, 1944). Since achievement was less real, the tension response may be attributable in greater degree to the aspiration. The relative equivalence of both Hope groups in Task II, irrespective of success or failure, points to interpretation along these lines.

The higher tensions of the Expect-Failure *Ss* suggest that they worked harder or were more excited in the second work situation, where the failure could be remedied. The lower tensions of the irrealistic failures suggest that among this group were individuals who subjectively withdrew from the situation, who were less stimulated or motivated by an unreal failure, who worked less hard. It is evident that failure, per se, serves to elevate muscle tensions, but in combination with the realism of aspiration, the effect depends upon whether the individual set himself realistically or irrealistically. This conclusion is supported by the views of other investigators in this area of study (Lewin et al., 1944).

In general, the results of this study resemble and may be associated with the findings of other investigations in which a psychological tension system is the intervening variable. To the extent that a parallel can be demonstrated between muscular tensions and the dependent variables employed in studies of conflict, perception and motivational theory, MAP may provide a basis upon which data can be reliably quantified.

Summary

The use of MAP as a dependent variable in level of aspiration experimentation has been shown to be feasible, and to yield results which agree with the findings of others with respect to the interaction effects of aspiration and achievement and the effects of success and failure.

The effect of the realism of aspiration on muscular tension depends upon whether *S* has succeeded or failed, and is manifested while he is engaged in work. The rate of tension increase is significantly greater in *Ss* who stated expectations and failed than in *Ss* who stated irrealistic aspirations and failed. Among *Ss* who succeed in a task, the tensions of the irrealistic are higher than those of the realistic aspirants..

Tension levels produced during work decrease in *Ss* who succeed and increase in *Ss* who fail, irrespective of the hopefulness or expectancy of aspiration.

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BACKWARD MEDIATED POSITIVE TRANSFER IN A PAIRED-ASSOCIATE TASK[1]

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Several investigators have shown the importance of the role of mediation in facilitating paired-associate learning (Bugelski & Scharlock, 1952; Irwin, 1951; Norcross & Spiker, 1958; Peters, 1935; Russell & Storms, 1955). The most recent demonstration of this was made by Norcross and Spiker (1958) in whose experiment an A-C list was facilitated following the learning of A-B and B-C lists. Presumably the B component common to the first two lists served to mediate the learning of the third through an A-B-C sequence. It has also been shown that *Ss* will associate word-pairs in both forward and backward directions (Harcum, 1953; Jantz & Underwood, 1958; Murdock, 1956, 1958). In the light of these findings, it may be predicted that there will be positive transfer to an A-C list following the acquisition of A-B and C-B (hence B-C) associations.

Peters (1935) conducted an experiment which failed to demonstrate that backward associations play a mediating role in learning. However, this may have been due to failure to control for *S* or list differences.

Storms (1958) has reported a study, the results of which are consistent with the backward mediation hypothesis. Sixteen female *Ss* learned a list composed of five A-C and five A-D word-pairs and then learned an A-B test list. The B and C words were chosen such that the B-C pairs were of high associative strength as indicated by the revised Kent-Rosanoff norms (Russell & Jenkins, 1954). It was discovered that the A-B pairs were learned best following the acquisition of A-C associations.

The results of a second investigation by Storms (1958) led him to reject a backward mediational interpretation of his previous findings. Fifty-nine *Ss* who had not participated in the first study were shown B words from that study and then were presented the corresponding C words and, for each, were asked to give the first response which came to mind. More C-B pairs were given than would be expected on the basis of available normative data.

These findings led Storms to assume that, during the first experiment, the presence of the B words in the A-B test list raised the associative strengths of the C-B pairs and hence facilitated learning through an A-C-B forward mediational sequence. This facilitation could have as easily come about through the formation of C-B associations during the learning of the A-B list with the obviously more difficult D-B control pairs failing to be learned at that time. Data recently obtained in these laboratories support this alternative account of Storms' findings. Twelve *Ss* learned lists made up of Storms' C-B and D-B pairs. The former were mastered on the average in 1.4 trials while 2.4 trials were needed to learn the latter pairs. Seven of 10 C-B pairs were learned in one trial, while only one D-B pair was mastered so readily.

The present experiments were performed to test the backward mediation hypothesis and were designed so that if B-C associations were formed during the learning of an A-C test list, resulting in facilitation through an A-B-C forward mediational sequence, this facilitation would occur under both experimental and control conditions.

METHOD

Three experiments were performed. Table 1 summarizes the way in which each was designed. In these experiments *Ss* were required to learn three lists. Each list consisted of 10 pairs of meaningful words and was presented by means of a memory drum.

[1] Defense Research Medical Laboratories Project No. 241, DRML Report No. 241-1, PCC No. D77-94-01-16, H. R. No. 193.

[2] Now at the University of Manitoba.

The *Ss* were assigned at random to two groups of equal size, each group being given a different form of List II with all *Ss* learning Lists I and III. It was predicted that the List III A-C pairs preceded by A-B and C-B pairs would be learned more readily than those preceded by A-B and C-D pairs. This design enabled each *S* to serve under both facilitation and control conditions and at the same time made possible detection of any differential difficulty which might arise between the two clusters of List III word-pairs.

Experiment 1.—The *Ss* were 20 male volunteers, all having had previous experience with paired-associate learning. Fifteen of these were members of the technical or clerical staff of the laboratories while the remaining five served in a professional capacity. Each of the three lists was presented in three different random orders so that serial learning would be minimal. On all lists a 4-sec. anticipation period was employed with the stimulus word appearing alone for 2 sec. and with the response word for 2 sec., with a 2-sec. period between where neither the stimulus nor the response word was shown. Lists I and II were presented until *S* had correctly anticipated each response word three times. A 2-min. rest was provided between the learning of these lists. The third list was given following a second 2-min. rest period and the experimental session was terminated when *S* had correctly anticipated all 10 response words in any one of the three orders in which they were presented.

Experiment 2.—Twenty male *Ss* participated, 10 of whom were in Exp. 1. All were volunteers, 18 being employed as technical or clerical staff. The procedure was the same as that of Exp. 1 except that different word lists were used and a 2-sec. instead of a 4-sec. anticipation period was employed. In this experiment the stimulus word appeared alone for 2 sec. and with the response word for 2 sec., with a 2-sec. blank period following the joint presentation of stimulus and response.

TABLE 1

EXPERIMENTAL DESIGN

Word-Pairs	Lists			
	I	II		III
	All *Ss*	Group I *Ss*	Group II *Ss*	All *Ss*
Five word-pairs	A-B	C-B	C-D	A-C
Remaining five word-pairs	A-B	C-D	C-B	A-C

TABLE 2

WORDS USED IN CONSTRUCTION OF LISTS FOR EXP. 3

A	B	C	D*
altar	boy	bat	cave
quiz	master	choir	music
index	finger	sore	back
sword	dance	square	play
relay	race	black	magic
knee	cap	bottle	opener
parcel	post	lamp	shade
harvest	moon	blue	cheese
lame	horse	riding	hood
nut	shell	crab	apple

* The first five words in Column D served as control words for Group I and the last five for Group II.

Experiment 3.—The *Ss* were 16 male and 16 female volunteers. Each of the males had participated in at least one of the two earlier experiments while the female *Ss* had not. Of the male *Ss*, 14 were technical or clerical staff members. Thirteen of the 16 females were employed in a secretarial capacity. A 2-sec. anticipation period was used with the stimulus word appearing alone for 2 sec. and with the response word for 2 sec. A new stimulus word was presented in the 2-sec. interval which followed. Each of the three lists was given in four different random orders and was composed of words which had not been used previously. These words are presented in Table 2. The *Ss* were engaged in conversation during the 2-min. rest between the presentation of Lists II and III. The experimental session was terminated after the List III word-pairs had been presented once in each of the four different random orders.

RESULTS AND DISCUSSION

In all three experiments Lists I and II as well as the two forms of the latter list were of comparable difficulty and were learned with relative ease. There was no indication that, while learning List II, *Ss* missed more C-D than C-B word-pairs. However, there was a tendency for par-

ticular word-pairs to be missed, but each served under both C-B and C-D conditions.

Experiment 1.—The difference between the mean number of correct anticipations on List III for the facilitation and control conditions was significant ($P < .001$). This difference was in the predicted direction with a mean value of 16.4 correct anticipations for the facilitation and 14.0 correct for the control condition. The analysis revealed no significant Groups × Conditions interaction, indicating that the two sets of List III word-pairs were of comparable difficulty. Although the backward mediation hypothesis was supported, the 4-sec. anticipation period may have enabled *S* to recall word-pairs from the first two lists while learning List III.

Experiment 2.—As in the previous experiment the difference between the mean number of correct anticipations on List III for the two conditions was significant ($P < .025$) and in the predicted direction with a mean value of 16.8 correct anticipations for the facilitation and 14.0 correct for the control condition. No statistically significant Groups × Conditions interaction was revealed. Again, although the mediation hypothesis was once more supported, the 2-sec. blank which followed the joint presentation of stimulus and response may have allowed *S* sufficient time to recall earlier word-pairs.

Experiment 3.—An analysis of variance of correct anticipations on List III is summarized in Table 3. (A similar summary for Exp. 1 and 2 is presented in the last three columns of this table.) The difference between the mean number of correct anticipations for the facilitation and control conditions was statistically reliable. This difference was in the predicted direction with a mean value of 9.2 correct anticipations for the facilitation and 6.3 correct for the control condition. All of the other main effects as well as their interactions failed to be statistically dependable. Since considerable control was exerted over *S*'s activities both before and during the learning of List III and

TABLE 3

ANALYSES OF VARIANCE OF CORRECT ANTICIPATIONS ON LIST III

Source	Experiment 3		Experiments 1 and 2		
	df	*MS*	*df*	*MS* (Exp. 1)	*MS* (Exp. 2)
Between *Ss*	31		19		
Groups (G)	1	52.56	1	8.10	28.90
Sex (S)	1	20.25			
G × S	1	4.01			
Error	28	17.74	18	69.18	83.20
Within *Ss*	32		20		
Conditions (C)	1	76.56**	1	57.60**	84.10*
C × G	1	0.07	1	0.10	1.60
C × S	1	1.01			
C × G × S	1	0.23			
Error	28	2.47	18	3.52	10.63
Total	63		39		

* $P < .025$.
** $P < .001$.

since 16 naive females gave results identical to those of males who had participated as *Ss* in the first two experiments, it may reasonably be concluded that backward associations play a mediating role in facilitating the learning of paired-associates.

Summary

The purpose of the study was to investigate the possibility of demonstrating backward mediated positive transfer in a paired-associate verbal learning task. In three separate experiments *Ss* were required to learn three lists each composed of 10 word-pairs. The first list was made up of A-B pairs and the third of A-C pairs while the second list was composed of five C-B and five C-D word-pairs. It was predicted that the five word-pairs of List III which were preceded by C-B pairs on List II would be learned more readily than those five preceded by C-D pairs. This prediction was supported by the findings of all three studies.

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TWO FACTORS AFFECTING STIMULUS GENERALIZATION ON A SPATIAL DIMENSION[1]

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Since an early stage in the development of the psychology of learning the phenomenon of stimulus generalization has been a matter of theoretical and factual importance. The basic notion that a response conditioned to one stimulus will be elicited by another similar stimulus has served as an explanatory concept in the interpretation of studies of transposition (Spence, 1937), gradients of approach and avoidance (Brown, 1942), conflict (Miller, 1959), and discrimination learning (Spence, 1937).

The crucial problem pointed out by the studies on stimulus generalization has been to attempt to discover the factors present in the distal stimulus situation which determine the organism's strength and/or frequency of response to a given generalized stimulus.

METHOD

The method used in this series of four experiments is similar to that used by Brown, Clark, and Stein (1958) in studying spatial generalization. The apparatus consisted of an opaque black screen with seven 6-w. lights mounted on it in a horizontal line facing *S*. The lights were mounted on the screen so that they could be moved from one position to another on a horizontal line. This allowed *E* to vary the distance between the lights. The electrical connections to the lights were arranged so that *E* could turn them on one at a time in any order desired.

On *S*'s side of the screen there were two response keys. The key to *S*'s right was marked "win" and the key to his left was marked "lose." Pressing either key turned off the stimulus light and illuminated a sign on *S*'s side of the screen which indicated whether the horses had "won" or "lost" the race represented in a particular trial. The sign which came on was determined by *E* independently of *S*'s response.

In all experiments *S* was seated in a chair at a distance approximately 2 ft. in front of the screen. The instructions given to *S* were essentially similar to those used by Brown, Clark, and Stein (1958). The order of presentation of the stimuli was predetermined and random with the constraints that no stimulus was presented more often than any other and that every stimulus followed every other stimulus equally often. Each stimulus was presented 24 times. This made a total of 168 trials. The reinforcements were arranged so that the horse symbolized by the middle light, i.e., Light 4, won 80% of the time, while all other lights won 20% of the time.

The *S*s were 100 students of general psychology at Duke University. Their ages ranged between 18 and 29. Both sexes were used as *S*s.

EXPERIMENT I

Brown, Clark, and Stein (1958) used a similar apparatus and procedure to obtain a generalization gradient which they interpreted as being a function of the spatial separation of the stimuli. The gradient, however, occurred in a situation where the individual stimuli were so far apart that they must have been easily discriminable, one from another.

In considering this problem the present author noted the possibility that the gradient produced under these circumstances might not be based solely on the spatial distances

[1] Based on a dissertation submitted to the graduate school of Duke University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author is indebted to Gregory A. Kimble, Chairman of the Doctoral Committee.

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between the stimuli, but rather on their relative spatial positions. This could well have been the case, since the stimulus lights were all simultaneously present and available to inspection, making it easy for *S*s to note the relationships among the lights. If such relationships, rather than the spatial separations of the stimuli, did provide the basis for generalization, then changing the distances between the stimulus lights should not affect either the shape or the height of the gradient, the reason for this being that changing the distance between the stimuli does not alter their ordinal positions although it would change their distance from the CS. If the gradient depended upon the absolute positions of the stimuli, then changing the distance between the lights should alter the shape and the height of the gradient.

Method

The apparatus and procedure are the same as outlined in the method section. Two groups of 10 *S*s each were used. For Group 3.0-NS, the stimuli were 3 in. apart and for Group 1.5-NS, the stimuli were 1.5 in. apart. The NS designation refers to the fact that no translucent screen was placed in front of the stimuli (to be used in a later experiment).

A third group, Group CP (Constant Position), of 10 *S*s was used as a control. In this group *S*s were presented with silhouettes rather than lights, in the same spatial locations. The method used for this group is very similar to that used by Bass (1958). If the basis of the generalization was a numbering of the stimuli and then generalizing on the basis of the numbers, as suggested by Razran (1949), the control group should show a gradient of generalization.

Results

For the statistical analyses, the two sides of the gradients were averaged since they seemed by inspection to be symmetrical. The responses to Light 4 (reinforced) were not included to eliminate elevation due to reinforcement rather than generalization. A comparison of the two resulting curves was made by a test of trend (Alexander, 1946). The F for between-group slopes is less than 1. The F for between-groups is 1.77. Both of these values are well below the .05 level. The F for overall slope is 24.90 ($P < .001$).

The procedure produced a stimulus generalization gradient. This is shown by the highly significant value of overall slope. However, the lack of significant differences between Groups 3.0-NS and 1.5-NS indicates that changing the spatial locations of the stimuli does not affect the gradient produced. The results of Group CP show that the basis of the gradient was not an implicit numbering of the stimuli but was, in some manner, dependent upon the locations of the stimuli. We must, therefore, conclude that the basis upon which the stimuli generalized was one of relative spatial location of the stimuli. If this hypothesis is correct, then any operation which will impede *S* in noting the relative positions of the stimuli should interfere with the production of the gradient. The next experiment is designed to test this hypothesis.

Experiment II

It was hypothesized that any operation which would prevent *S* from noting the relationships among the stimuli should prevent the occurrence of the gradient. Since it was necessary for *S* to be able to see more than one stimulus at a time in order to perceive their relative positions, preventing *S* from seeing more than one stimulus at a time should eliminate the gradient based upon their ordinal relationships.

On the other hand, if the stimuli were very close together, a gradient might be formed on the basis of their spatial separation from the CS, even if only one stimulus at a time could

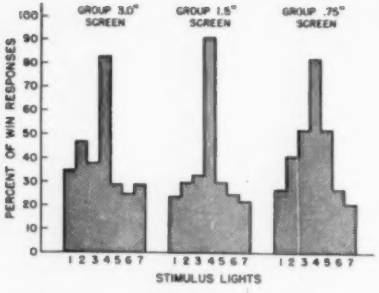

FIG. 1. Comparison of Groups 3.0-S, 1.5-S, and .75-S.

be seen. This should occur when *S* is no longer sure as to the identity of an individual stimulus. That is to say, when discrimination between individual stimuli becomes difficult, generalization may occur.

Method

The apparatus and procedure were the same as in Exp. I. However, a translucent screen was placed in front of the stimulus lights which effectively prevented *S* from seeing more than one stimulus at a time. Also, the instructions were changed to eliminate mentioning the number of "horses" that were being used. The *S*s were questioned following the experiment as to the number of stimulus lights they believed to have been present.

Three groups of 10 *S*s each were used. For Groups 3.0-S, 1.5-S, and .75-S the stimulus lights were 3.0, 1.5, and .75 in. apart, respectively. The designation "S" refers to the presence of the translucent screen.

Results

Figure 1 shows the performance of each group plotted in percentage of "win" responses to each stimulus light. As the intervals between the stimuli become smaller, a gradient emerges. Table 1 presents the tests of trend for each group. For group slope the F for Groups 3.0-S, 1.5-S, and .75-S are not significant, almost significant at the .05 level, and significant at the .001 level, respectively.

In order to determine whether the presence of the screen made a difference at wide stimulus intervals, a comparison was made between Group 3.0-NS from Exp. I and Group 3.0-S from Exp. II. This is presented in Table 2. The F for between-group slopes is 78.79 ($P < .001$) and the F for between-group means is 34.70 ($P < .001$).

At wide stimulus intervals the presence of a screen which prevents *S* from seeing more than one stimulus at a time does prevent the appearance of a generalization gradient. This demonstrates that the gradient obtained at the wide stimulus separations used in Exp. I was based upon the relative stimulus positions, and not on the distance of the stimuli from the CS. When the interval between the lights is extremely small, even with a screen, a gradient appears. This suggests that a gradient based upon the degree of stimulus separation may also

TABLE 1

TESTS OF TREND FOR GROUPS IN EXP. II

Source	*df*	3.0 in.		1.5 in.		.75 in.	
		MS	*F*	*MS*	*F*	*MS*	*F*
Group deviation from linearity	1	.82	<1	.14	<1	9.19	1.37
Between-individual slopes	9	6.01	<1	16.94	2.95	8.96	1.34
Group slopes	1	.45	<1	24.20	4.22	183.01	27.36***
Between-individual means	9	4.28	<1	19.08	3.32	7.48	1.12
Individual deviations from estimates	9	8.13		5.74		6.69	

*** $P < .001$.

TABLE 2

TESTS OF TREND BETWEEN GROUPS 3.0-NS AND 3.0-S

Source	*df*	*MS*	*F*
Between-individual slopes	18	5.26	5.80***
Between-individual means	18	13.20	14.61***
Group deviation from estimate	1	4.26	4.69*
Between-group slopes	1	71.55	78.62***
Between-group means	1	31.55	34.63***
Overall deviation from linearity	1	.60	<1
Overall slope	1	88.51	97.26***
Individual deviation from estimate	18	.91	

* $P < .05$.
*** $P < .001$.

exist when *S* is confused as to the identity of the stimuli. In Group .75-S less than 25% of the *S*s could even guess the number of stimuli being used, while in Group 3.0-S all *S*s correctly guessed the number of stimuli.

On the basis of Exp. I and II, it is apparent that both the number of intervening stimuli and the spatial distance of the stimuli from the CS may serve as the basis for stimulus generalization along a spatial dimension. The latter serves as a basis when *S* is confused as to the identity of the stimuli. The former serves as the basis when *S* is allowed to see all of the stimuli simultaneously and circumstances make any confusion unlikely.

EXPERIMENT III

In Exp. I it was shown that *S* can form a gradient even when the stimuli are easily discriminable one from another, provided that he can see all the stimuli simultaneously and note their relative positions. This condition brings to mind the explanation of stimulus generalization proposed by Lashley and Wade (1946) and, more recently, the unit hypothesis of Mednick (1960). Lashley and Wade believed that the gradient of stimulus generalization was the result of *S* having learned a dimension by comparing the stimuli. If this view is correct, then in the present situation *S* only needs to be able to see all of the stimuli simultaneously during the initial phase of training, and after this he should have learned the locations of the stimuli in the series and be able to respond to them even though comparison of the stimuli is no longer possible.

Method

The apparatus and procedure are the same as in the previous experiments. One group of 10 *S*s, Group 3.0-PS, received the last 84 trials with the lights 3 in. apart and with the translucent screen in place in front of the stimuli. The PS designation indicates that the screen was present part of the time. We see by this arrangement that the first half of the trials of this group are comparable to the same trials for Group 3.0-NS of Exp. I, while the last trials of this group are comparable to the same trials of Group 3.0-S of Exp. II. Group 3.0-NS has been shown to produce a gradient, while Group 3.0-S has been shown not to produce a gradient.

Results

Figure 2 presents a comparison of the last 84 trials of Groups 3.0-PS and 3.0-NS. It can be seen that although the screen was in place in

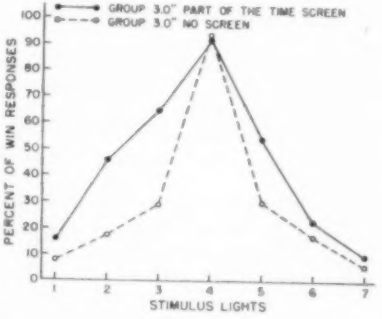

FIG. 2. Comparison of Groups 3.0-NS and 3.0-PS for the second half of trials.

Group 3.0-PS during these trials, a very impressive gradient was formed. The screen actually seems to have accentuated the gradient in this case. This contrasts sharply with the earlier finding with Group 3.0-S where no gradient was formed at this degree of stimulus light separation when the screen was in place for all trials. Table 3 presents a statistical comparison of Groups 3.0-NS and 3.0-PS. The F for between-group slopes is 9.00 ($P < .005$).

These results support the Lashley and Wade hypothesis that the relative positions of the stimuli are learned by a comparison. Apparently S need only receive a small amount of training in comparing the stimuli to learn the relationships and to be able to continue to produce a gradient even when a comparison is no longer possible.

In observing this learning of relationships between stimuli, we must wonder how many different sets of relations an S must bring to any experimental situation. It could be that all stimulus dimensions are originally based on the external relationships among discrete stimuli, but that S internalizes these relationships through learning and become available for the control of behavior when the original relationship is no longer present. Space becomes a construct formed in order to relate various stimuli. In this sense, response to the space between stimuli is impossible. However, in the act of observing the relative positions of stimuli internal proprioceptive cues are produced which are able to internalize relationships and thus make it appear that our reactions are to an absolute space.

TABLE 3

TESTS OF TRENDS BETWEEN TRIALS 85–168 FOR GROUPS 3.0-PS AND 3.0-NS

Source	*df*	*MS*	*F*
Between-individual slopes	18	14.06	2.01
Between-individual means	18	6.72	<1
Group deviation from estimate	1	1.70	<1
Between-group slopes	1	63.02	9.00**
Between-group means	1	241.00	34.43***
Overall deviation from linearity	1	5.03	<1
Overall slope	1	774.34	110.62***
Individual deviation from estimate	18	7.00	

** $P < .01$.
*** $P < .001$.

EXPERIMENT IV

Experiment II showed that, at very small stimulus separations, a gradient appeared when S was unable to compare the stimuli. It was suggested that the gradient resulted from a confusion by S as to the identity of the various stimulus lights. This is to say that under certain conditions, S will generalize insofar as he cannot discriminate. This evidence tends to support the position proposed by Kalish (1958). The purpose of Exp. IV was to examine the processes of discrimination and generalization under circumstances more nearly identical than those used in Exp. I–III.

Method

The apparatus and procedures were the same as in Group .75-S in Exp. II. The screen was in front of the stimulus lights and the lights were .75 in. apart. In the present experiment, however, only 98 trials were used and the center light received 100% reinforcement and the other lights received no reinforcements. Three groups of 10 *S*s each were used. These groups differed only in the instructions received by *S*s.

Group NK (no knowledge of the reinforcement values) received the same instructions as Group .75-S of Exp. II. Group COK (knowledge of center light only) received the same instructions as Group NK

with the additional information that the center light would "win" every time that it raced. Group AK (knowledge of the reinforcement values of all the stimuli) was given the same introduction and instructions as Group NK with the additional information that the center light would always "win" and that all other lights would always "lose." This condition is essentially identical to a psychophysical study of discrimination.

Results

Figure 3 presents a comparison of the error scores by blocks of seven trials for each group. The rates of improvements for the three groups are very different, and the rate of improvement varies directly with the amount of knowledge of the reinforcement values given to *S*s. An analysis of variance of the last 28 trials shows the *F* for between-groups to be 1.07. This value falls far short of significance at the .05 level. We therefore conclude that during the last four presentations of each stimulus light the groups do not differ significantly; however, the rates at which the groups approach this level are markedly different depending upon the amount of information given to *S*s as to the reinforcement values of the stimuli.

The results of this experiment seem

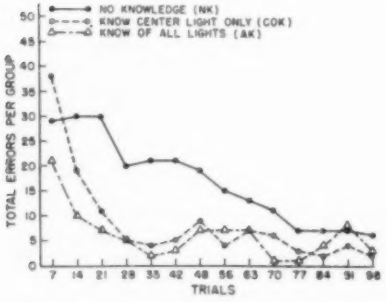

FIG. 3. Comparison of error scores of Groups NK, COK, and AK.

to indicate that, with the acquisition procedure used here, discrimination is the limit which the generalization gradient approaches as *S* learns the reinforcement values of various stimuli on the dimension. By this hypothesis, the relationship between discrimination and stimulus generalization is one which may vary, depending on the situation of testing. If the conditions of testing maximize the information obtained by *S*, then the gradient of generalization will closely approximate the gradient of discriminability. If the conditions of testing minimize the amount of information that *S* receives, then there will be a great difference between the generalization gradient and the gradient of discriminability.

DISCUSSION

On the whole, these experiments have demonstrated that either the distance or the relative position of the generalized stimulus from the CS can produce a dimension of similarity upon which *S* may form a stimulus generalization gradient. One of the conditions found to be necessary for the formation of a gradient based on a relational dimension is the simultaneous presentation of the stimuli which enables *S* to compare the stimuli and learn the dimension.

The importance of the relational ordering of stimuli is probably very great. Modern S-R theory of transfer of training usually makes the assumption of stimulus generalization as a basic postulate, yet, in most transfer studies it is very difficult to believe that the transfer occurs because *S* confuses the test situation with the training situation. The existence of a type of stimulus similarity which is based on the relational aspects of the situation seems to be a necessity.

Even situations which have previously been considered in terms of stimulus separation could well be re-examined in the light of relational cues. For example, the studies on the goal gradient might well be thought of as determined

by the ordinal spatial relationships of a series of distinctive stimuli approaching the goal. Notions such as this seem to lie behind Miller's (1959) liberalization of S-R theory to include relational cues as determinants of behavior.

The present experiments have demonstrated that in the acquisition situation the relationship between generalization upon an absolute dimension and discrimination is that of a function approaching a limit. The rate of approach to the limit formed by discriminability of the stimuli is determined by the amount of knowledge given to *S* as to the reinforcement values of the various stimuli. This result supports the position of Brown, Bilodeau, and Baron (1951) who stated: "The relation of psychophysical studies to generalization experiments might be clarified if they were treated as two extremes of a series of experiments arranged according to the degree to which their procedures permit the appearance of empirical generalization" (p. 60). This is essentially what was done in Exp. IV. The variable which determined the position on the continuum between discrimination and generalization procedures was the amount of information given *S* as to the reinforcement values of the stimuli.

As a final comment, it seems important to state that the author does not believe that the two factors demonstrated in this study exhaust the possibilities of types of factors which may determine stimulus generalization. These types, as well as others, may well act simultaneously in any complex situation to produce the final gradient.

Summary

The main purposes of this study were, first, to demonstrate the existence of two factors of stimulus similarity as bases of spatial stimulus generalization, and second, to investigate the conditions under which each type of gradient appears.

The general method was similar to the procedure employed by Brown, Clark, and Stein (1958) with human *Ss*. A comparison was made between the gradients formed to the stimuli when different distances of stimulus separation were employed. When all of the stimuli could be seen simultaneously, the gradients were determined by the relational positions of the stimuli rather than by their distance from the CS. When the stimuli could not be seen simultaneously a gradient was formed only when the stimulus lights were placed very close together and *Ss* were no longer sure as to the identity of the individual stimuli. If, however, *Ss* saw all of the stimuli sources simultaneously during early trials, they still produced a gradient in later trials even though they could no longer see all stimulus sources simultaneously.

Finally, *Ss* who were permitted to utilize the spatial separation of the stimuli produced a gradient which was related to discrimination. The relationship was one of a function approaching a limit. The rate of approach was determined by the amount of information that *S* had as to the reinforcement values of the stimuli.

These findings were discussed in terms of their implications for theories of stimulus generalization.

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A CONDITIONED INHIBITORY PROCESS IN EYELID CONDITIONING[1]

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A phenomenon sometimes encountered in eyelid conditioning is a diminution in the magnitude of the unconditioned reflex which develops with training. Previous investigators have usually interpreted this effect in sensory terms as adaptation to the UCS or in response terms as reflex habituation (Hilgard & Marquis, 1940). The experiment to be described here provides data in support of a different explanation which treats the reduction as a form of conditioned or associative inhibition (Guthrie, 1938).

The basic point is easy to make with the aid of the response record presented in Fig. 1. In the study from which that record came (Dufort & Kimble, 1958), the usual test with CS and UCS alone were followed by a series of trials as follows: On Trials 1–20 the CS and UCS were paired at a 0.5-sec. interval. Trials 21–40 consisted of 20 presentations of the UCS alone. Trials 41–60 were CS-UCS pairings, at the same interval as before. Figure 1 presents a selection of representative responses obtained from an *S* who did not, in the usual sense, condition. The upper left-hand panel of Fig. 1 presents a tracing of a response to the UCS obtained prior to conditioning, on a test trial with the CS omitted. The other panels are records taken on a series of trials selected to illustrate the conditioned inhibitory process. Trials 1, 10 and 20 reveal a gradual reduction in the amplitude of the UCR which might be interpreted as adaptation or habituation, were it not for the evidence to the contrary on Trials 21–40. These trials, which were administered without the CS, evoked UCRs with magnitudes at least as great as on the trial prior to conditioning, suggesting that the response diminution apparent on Trials 1–20 is under the control of the CS. This interpretation receives further support on Trials 41–60 when the CS was reintroduced. On the very first of these trials the form of the response changed, and there was a slight reduction in magnitude. By Trial 43 it was smaller than on Trial 20. Later trials produced responses with magnitudes sometimes smaller and sometimes greater than on Trial 43. The general picture, thus, is one in which the CS comes to occasion an inhibition of the UCR rather than a CR. Since the process is under the control of the CS, it seems appropriate to call it conditioned inhibition.

It should be stressed that the record presented in Fig. 1 is an extreme example. Although many *S*s show such decreases in response amplitude, there are few who show it so dramatically. One possibility is that a larger number of trials would bring out the effect in more substantial proportions. To investigate this possibility and to examine the effect of one further variable of possible importance, four different groups of *S*s were given 50 conditioning trials at four different interstimulus intervals. Following conditioning they received 10 trials with the UCS alone, to obtain a measure of response amplitude in the absence of the CS. Our main interest is in the increase in amplitude of the UCR on this latter series of trials.

METHOD

Apparatus.—The apparatus employed in this study was the same as that used in a previous experiment (Dufort & Kimble, 1958). The CS was the onset of a single neon light, recessed about .25 in. behind a

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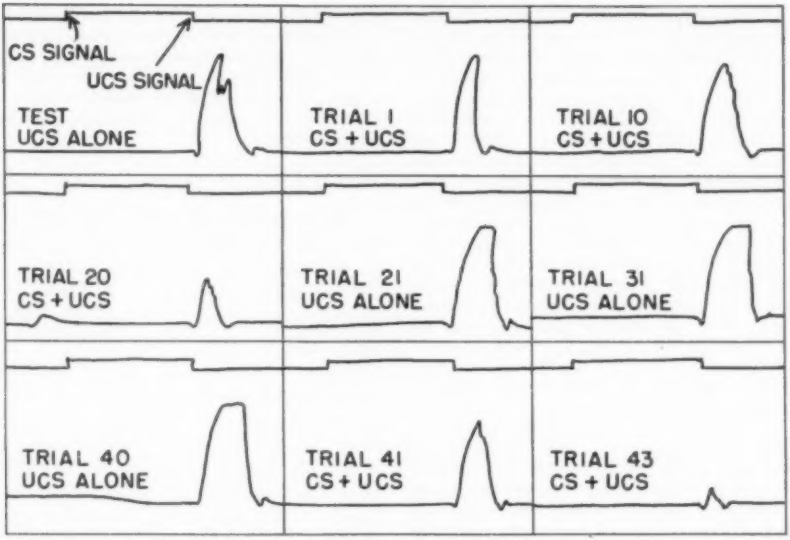

FIG. 1. A selection of response records showing inhibition of the UCR on trials with the CS, and recovery from this inhibition on trials without the CS. The difference in amplitudes on Trials 20 and 21 is typical of the difference measured in obtaining an index of inhibition. CS and UCS signals always appear whether or not the stimuli were presented.

3.5 × 8.0-in. flat black panel, 20 in. directly ahead of *S* and visible through a hole .5 in. in diameter. Its intensity was about .01 apparent ft-c. The UCS was an air puff of .05-sec. duration delivered to the right eye of *S* at a pressure of 80 mm. of mercury. The duration of the CS for all groups was .05 sec. longer than the interstimulus interval, and the UCS was delivered during the .05-sec. period, so that the CS and UCS terminated together.

Eyelid responses were recorded by a system consisting of a microtorque potentiometer, the arm of which was linked to a false eyelash worn by *S*, a Hunter Eyeblink Amplifier and an inkwriting response recorder.

Subjects and design.—The *S*s in the experiment were 64 Duke University undergraduates, fulfilling part of a requirement for the Introductory Psychology course. These *S*s were assigned at random to four groups and were conditioned at CS-UCS intervals of 0.25, 0.50, 1.0, or 2.0 sec. Each subgroup consisted of 8 men and 8 women.

During the experiment, *S* sat in a brightly lighted, sound-deadened chamber, with his chin in a chin rest, watching the panel where the CS appeared. Trials were administered automatically at irregular intervals ranging from 9 to 22 sec. and averaging 15 sec. For each *S* the sequence of events was the same and consisted of four phases as follows: (*a*) 5 test trials with the CS alone; (*b*) 5 test trials with UCS alone, to determine initial reflex amplitude; (*c*) 50 conditioning trials with the CS and UCS paired at the appropriate interval; and (*d*) 10 test trials with the UCS alone again.

Measures.—The records were read by two experienced *E*s, on a schedule according to which each read half of the records for each group. In a few records which were difficult to interpret, the two *E*s (or one of the *E*s and the senior author) consulted and came to a joint decision. As is always the case, the specification of CRs and UCRs required a number of somewhat arbitrary criteria. The most important of these were the following: (*a*) All anticipatory responses were considered CRs. Those *S*s who gave more than three in the "voluntary" range on the last 20 trials were discarded. These ranges, established on the basis of previous research (Boneau, 1958), were from 0.0 to 0.15, 0.30, 0.60, and 1.2 sec. for the 0.25-, 0.50-, 1.0-, and 2.0-sec. intervals, respectively. The use of

this criterion meant that some 4% of the CRs counted in this experiment fell in the so-called "voluntary" range. The very great majority of them occurred early in conditioning when the mean latency of the CR is somewhat shorter than later in conditioning (Boneau, 1958). Moreover, their form tended to be that of true CRs rather than the characteristically different form of the voluntary response. (*b*) A CR also had to meet a 2-mm. amplitude criterion. In measuring the amplitude of responses it was necessary to pay specific attention to the baseline problem. For most *Ss*, the baseline from which a response occurs is easy to determine, and tends to remain stable throughout conditioning (cf. Fig. 1). There are, however, occasional cases with considerable "noise" on the baseline. On these records, *E* ruled a straight line through the apparent average of these deviations, and measured the amplitude of the UCR from it. In these cases, to count as a CR, the response had to have an amplitude 2 mm. greater than what appeared to be the upper limit of the range of random deflections. It should be emphasized that this problem arises in only a limited number of *Ss*. (*c*) A UCR was defined as any response which followed the onset of the UCS. Its amplitude was measured from the baseline described above. Where the UCS produced multiple blinks, the amplitude of the first was counted the UCR.

The most important data obtained in this experiment involve the UCR amplitudes just described, the specific concern of the study being the differences between these measured in the presence of the CS during conditioning and in its absence after conditioning. In obtaining these differences one main complication had to be faced: Almost all of the CRs blended with the UCRs, making statements of UCR amplitude somewhat ambiguous for trials on which CRs occurred. Because of this ambiguity, measurements of UCR amplitude were made only on trials on which no CR occurred. The specific measure employed was the difference in millimeters between the amplitudes of the last five UCRs in conditioning and the first five in the post-conditioning series on which no random blink or other complication in the response record occurred. This rule of limiting measurements of UCR amplitude to trials on which no CR occurred created problems of its own, particularly in analyses involving the interstimulus interval variable. This is because the responses measured occurred, on the average, earlier in conditioning in the groups conditioned at favorable intervals. This effect works against the possibility of obtaining significant interstimulus interval effects on the inhibitory process, and may have contributed to the failure to obtain a significant influence of this variable on the inhibitory mechanism, as is described in the results section.

Results

Mean percentages of CRs on the last 20 conditioning trials (Trials 31–50) were 0.6, 40.9, 41.2, and 26.9 for the 0.25-, 0.50-, 1.0-, and 2.0-sec. groups, respectively. These numbers show the general trend obtained in previous studies of the CS-UCS interval, although conditioning was slightly better at the 1.0-sec. interval than at the 0.5-sec. interval which is usually found to be optimal. The most likely reason for this is that the longer CR range in the 1.0-sec. condition affords a greater opportunity for the occurrence of a random response. The differences among the four groups are statistically significant when evaluated by the methods of analysis of variance ($F = 5.047$, $df = 3/60$, $P < .01$). Unfortunately the validity of this analysis is vitiated somewhat by heterogeneity of variance, as revealed by Bartlett's test ($\chi^2 = 28.16$, $df = 3$, $P < .01$). The commonly cited study of Norton (Lindquist, 1953) and the fact that the form of the interstimulus interval function has been repeatedly found to be generally like that obtained here, however, suggest that these results are dependable in spite of the violation of the assumptions behind the analysis of variance.

Data on the mean amplitudes and variances of the UCR, with which this study is mainly concerned, are summarized in Table 1. Column A presents data obtained on the pretest trials with the UCS alone. Column B presents data on the last five conditioning trials on which no CR oc-

TABLE 1

MEANS AND VARIANCES OF UCR AMPLITUDES AND DIFFERENCE MEASURES: MAIN EXPERIMENT

CS-UCS Interval	Measure	A Pretest	B Last 5 Trials	C Posttest	A-B	A-C	C-B
.25-sec.	Mean	22.88	17.30	18.81	5.58	4.06	1.51
	σ^2	22.69	59.70	26.77	50.98	25.78	12.85
.50-sec.	Mean	23.74	17.24	20.40	6.50	3.34	3.16
	σ^2	18.78	43.12	25.60	46.87	21.20	38.59
1.00-sec.	Mean	23.33	20.96	22.77	2.37	.56	1.81
	σ^2	15.54	13.79	21.30	20.90	21.67	9.09
2.00-sec.	Mean	23.99	19.82	20.04	4.16	3.94	.22
	σ^2	14.56	40.12	35.92	26.80	17.72	8.62
Overall means					4.65	2.98	1.68

curred. Column C presents amplitudes on the posttest trials without the CS. Column A-B presents the differences between UCR amplitude on the pretest and the last five conditioning trials without a UCR; Column A-C presents the differences between UCR amplitude on the pretest and posttest trials, both conducted without the CS. Column C-B presents the differences between UCR amplitude on the last five conditioning trials without a CR and on the series of posttest trials. This last is our measure of stimulus-controlled inhibition. The first three columns of data seem to require no special comment. Three separate analyses of variance indicate that there are no significant differences among the means in these columns. The largest F ratio was obtained on the analysis of the data is Column C ($F = 1.598$, $df = 3/60$, $.25 > P > .10$).

The various difference scores were also subjected to statistical analysis. The values in Column A-B correspond to the habituation effect so often observed in conditioning. The overall magnitude of the effect is highly reliable ($t = 4.36$, $df = 60$, $P < .001$); but there is no significant difference among groups in degree of habituation ($F = 1.418$, $df = 3/60$, $P = .25$). It will be recognized that the measures in Column A-B actually result from the summation of the two effects, a true habituation involving the reflex mechanism directly and the stimulus-controlled process being investigated in this study. In order to determine whether habituation uncontaminated by the stimulus-controlled component occurred, it is necessary to deal with the differences in Column A-C. These measures are based on the UCR amplitudes before and after conditioning, but in the absence of the CS in both cases. This measure again reveals that the decrement in amplitude is significantly different from zero when the groups are combined ($t = 3.624$, $P < .01$), but there are no significant differences among the groups ($F = 1.994$, $df = 3/60$, $.25 > P > .10$).

Greatest interest in the results of this study centers in the gain scores presented in Column C-B in Table 1. These measures reflect the increase in UCR amplitude from the end of conditioning to the posttest trials. As an overall effect this gain is significant ($t = 2.279$, $.05 > P > .02$).

The differences among the groups, however, are not significant ($F = 1.350$, $df = 3/60$, $P > .25$). Thus the reality of an inhibitory process under stimulus control has apparently been demonstrated; but a valid relationship between the magnitude of this process and the interstimulus interval has not been.

These general statements obscure certain suggestive evidence obtained by a more thorough analysis of the data. As will be shown, there is an indication that the inhibitory process, though real and statistically dependable, actually occurs in only about half of the *Ss*. And the interstimulus-interval function, though statistically unreliable in this analysis, may actually exist. Some indication of these possibilities may be obtained by a closer inspection of the data in Column C-B of Table 1, where one sees that the inhibitory measures form a pattern which parallels the usual interstimulus interval function in eyelid conditioning. Obviously, this is a possibility worth looking into, and one which would be of great interest if it were not an accident of sampling. Moreover, the sizes of the variances suggest another important fact: that many of the *Ss* showed, not a gain on the posttest trials with the UCS alone, but a loss. To pursue some of these suggestions further, the 16 *Ss* in each interstimulus-interval group were split at the median gain (C-B) score and two further analyses were carried out.

The first fact to come from an analysis of the C-B scores of these dichotomized groups was that the 32 *Ss* who showed less than the median amount of gain actually showed a small (.97 mm.) but significant average loss in UCR amplitude ($t = 2.75$, $df = 31$, $P = .01$) on the posttest trials. This outcome indicated the desirability of evaluating the pattern of gain scores on the group which, on the average, showed a gain. Accordingly, the data for the *Ss* above the median were analyzed separately. This procedure produced a small increase in the significance level of the interstimulus interval effect; but it was still far short of the usually accepted minimum values ($F = 1.72$, $df = 3/28$, $.10 < P < .20$).

Subexperiment.—As was mentioned in connection with the description of Fig. 1, *Ss* showing a pronouncedly inhibited UCR are rare. For this reason, such *Ss* in an experiment performed since the one just described have received a special treatment intended to test the validity of the unreliable trend obtained in this study. Our hypothesis was that there might actually be a relation of the amount of UCR diminution to the length of the interstimulus interval, which had failed to attain statistical significance in the main experiment because of the great variability in the data. In approximately 100 *Ss*, there were 6 who showed marked habituation of the UCR. Of this group, 5 were tested under identical conditions. Since their results have a direct bearing upon the outcome of the main study, they will be reported here.

The conditions of test for these *Ss* were as follows: (*a*) First there were 2 preliminary trials with the CS alone, 3 trials with the UCS alone, and 20 conditioning trials at an average intertrial interval of 20 sec., in which the CS and UCS were paired at a 0.5-sec. interval. (*b*) The *Ss* showing a UCR diminution of approximately 50% on these 20 conditioning trials then received 5 trials with the UCS alone to make certain that the response recovered its amplitude in the absence of the CS, and to provide

a baseline for later measurement. (*c*) Finally, these *S*s received 10 reinforced trials at each of the four different CS-UCS intervals used in the main study (i.e., 0.25, 0.50, 1.0, and 2.0 sec.). The order of these trials was random, with the constraint that each interval had to appear twice in each block of 8 trials.

The results of this subexperiment supported the hypothesis. For the 0.25-, 0.50-, 1.0-, and 2.0-sec. intervals, mean UCR amplitudes were 20.0, 16.6, 18.8, and 21.0 mm. These values differed from the mean amplitude (24.3 mm.) on the immediately preceding test trials by 4.3, 7.7, 5.5, and 3.3 mm., respectively. The pattern of these values is very much like that in Column C-B of Table 1. Presumably because of the relatively great statistical precision obtained by using each *S* as his own control, the differences among these means are significant ($F = 3.52$, $df = 3/12$, $P = .05$) when evaluated by a Treatments-by-*S*s analysis of variance.

Discussion

The results just presented demonstrate the existence of a true habituation effect in that there was a significant difference in UCR amplitude before and after conditioning. More importantly, however, there occurs another inhibitory process which is under stimulus control. The evidence for this is that withholding the CS restores a considerable proportion of the amplitude loss during conditioning. In addition, there is tentative evidence that the amount of this stimulus-controlled inhibition varies with the interstimulus interval just as conditioning does. Because of these resemblances to other conditioning, we are inclined to call this a conditioned, or associative, inhibition.

The importance and more basic nature of this inhibitory process remain to be assessed. As might be expected, one of its characteristics is that it is associated with poor conditioning. The relationship, however, is neither simple nor linear. On the average, the high-inhibition *S*s gave fewer CRs than the low-inhibition *S*s; but, evaluated for the last 20 trials, the difference was not significant ($F = 1.110$, $df = 1/56$, $P > .25$). On the other hand, the six *S*s showing the greatest amount of conditioned inhibition gave no CRs in the entire experiment. Similarly, the 5 *S*s in the subexperiment who were selected for showing substantial amounts of inhibition gave no anticipatory blinks in their 20 original conditioning trials. Apparently a marked interference with conditioning occurs when the amount of conditioned inhibition is great.

As to a more exact specification of the nature of the inhibitory process, several possibilities (at several levels) appear to have some explanatory potential when applied to these results.

First, the process may be a general characteristic of reflex action. Hilgard (1933) obtained results very similar to the present ones in a study which demonstrated that a preceding auditory stimulus was capable of reducing the magnitude of a blink to light. In discussing his results, he presented evidence from previous studies to show that other UCRs can be inhibited by prior stimulation, which suggests that the phenomenon may reduce to a matter of the automatic interaction of reflex mechanisms. If this were so, the designation, *conditioned* inhibition, would be inappropriate. An argument against this interpretation is that the inhibitory phenomenon occurred in only about half of the *S*s in this experiment, and failed to appear in some *S*s in other investigations where such an effect was obtained (Hilgard, 1933; Pfaffmann & Schlosberg, 1936). One would expect an effect which occurs at a true reflex level to be more dependable.

Another possible explanation is that the inhibitory process is merely a voluntary or semivoluntary resistance against "being made to blink." If this were so, the inhibition of the UCR might be expected to occur suddenly, after a very few

conditioning trials. Curves of UCR-amplitude plotted against trials (not presented in this report) and examination of individual records show what seems to be a gradual diminution in amplitude. This result argues against such a "voluntary nonresponder" interpretation.

Still another possibility is that the inhibitory process is related to personality variables. Pfaffmann and Schlosberg (1936) report that a tendency to inhibit the UCR is associated with a low level of conditioning in normal *Ss* and a relatively high level of conditioning in schizophrenics. And Eysenck (1955) found that hysterics (whom he regarded as inhibitable *Ss*) were inferior in conditioning to other neurotics. Our data, however, have no bearing on this possibility.

A final possibility is that we are dealing with something resembling Pavlov's (1927) inhibition of delay which, in salivary conditioning, prevents the occurrence of the CR until just before the appearance of the UCS. Although no such demonstration seems to have been made, it is possible that inhibition of delay continues to operate, at least until the appearance of the UCS, and that it inhibits the response to it. It is known that a negative CS in a discrimination experiment when paired later with the UCS tends to inhibit the response to this latter stimulus, suggesting that a similar effect might be associated with the CS. Such an explanation is, of course, purely descriptive; but it does suggest an experiment. It should be possible to disinhibit the reflex by introducing an extra stimulus just before or just after the onset of the CS (Rodnick, 1937).

Obviously the results of this study do not discriminate among these, or other, conceivable alternatives. Various lines of investigation are suggested which differ for the various possibilities.

Summary

In a main experiment, four groups of 15 human *Ss* each had their eyeblinks conditioned at CS-UCS intervals of 0.25, 0.50, 1.0, and 2.0 sec. During this conditioning the amplitude of the UCR diminished. Tests later, in trials with the UCS alone, showed a significant gain in UCR amplitude. The average amount of this gain varied with the interstimulus interval in a way which resembled the usual function relating conditioning to the same variable, but this trend was not statistically significant. A subexperiment, with 5 specially selected *Ss* conditioned at all four intervals, confirmed the results of the main experiment and also provided statistically reliable evidence for the interstimulus-interval function suggested by the results of the main experiment. This demonstration of a response diminution under stimulus control seems to be a form of conditioned inhibition. Several possible mechanisms are suggested.

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DIFFERENTIAL MONETARY GAINS IN A TWO-CHOICE SITUATION[1]

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Although many studies (e.g., Grant, Hake, & Hornseth, 1951; Humphreys, 1939; Siegel & Goldstein, 1959) have been concerned with the probability of response in a two-choice situation, only one (Edwards, 1956) has dealt with the problem of differential monetary rewards. Edwards' study showed that *Ss* do not simply match the relative frequencies of the two events when differential payoffs are used. He therefore suggested two alternative models to deal with differential monetary rewards. The first is the Expected Payoff (EP) Matching Generalization.[2] This model predicted better than the simple matching solution but still did not give accurate estimates of the final asymptotes. The second model utilizes Savage's (1951) notion of regret, or loss, and is called the Relative Expected Loss Minimization (RELM) rule. Edwards found the RELM rule to be relatively successful in predicting the rank order of the asymptotes obtained from 24 experimental conditions. The fact that the relationship between the probability of choice and the RELM values was linear and that the correlation between these variables was .96 was further support for the rule. The present study was designed to provide additional data relating to differential reward and to further explore various quantitative models which might be applicable.

[1] This experiment was supported by funds provided by the United States Navy Training Devices Center under Contract N61339-588.

[2] Edwards (1956) originally called this the Expected Value Matching Generalization. In a recent personal communication, he suggested that since the solution is derived from expected payoffs, it should bear that name.

METHOD

Apparatus.—Four *Ss* were used in each experimental session. Each *S* was seated before a panel 8¼ in. high and 7 in. in width which was set at a 45° angle. The panels were separated by partitions, preventing each *S* from observing the responses of the others. Each panel consisted of four lights and two switches which were arranged in two columns. The upper two lights were red and green and constituted the informing lights. Both the lower lights were amber and indicated choice for each trial. The switches controlled the choice lights and were used by *Ss* when they made their predictions.

Located on a table behind *Ss* was a Western Union tape transmitter which automatically controlled the sequence of the informing lights. The sequence was constructed from a table of random numbers with the restrictions that each light appeared a designated percentage of the time, only one light was correct on each trial, and no light appeared more than five consecutive times. A buzzer served as a signal for *Ss* to make their predictions.

Procedure.—The 32 *Ss* were randomly assigned to eight equal groups in a 4 × 4 latin square design. The latin letters were the gain ratios (i.e., the ratio of the amount gained by correct prediction of the less frequent light relative to that gained by correct prediction of the more frequent light) of 1 chip to 1, 2 chips to 1, 3 chips to 1, and 4 chips to 1. Table 1 shows the four sequences that were used. In four of the groups, *Ss* performed for the four days with the frequency of lights being 60% and 40%, while the other groups performed with frequencies of 80% and 20%. In all cases, the light with the lower frequency of occurrence yielded the higher gain. Each combination of frequency and gain appeared equally often in the right and left panel positions.

TABLE 1

LATIN SQUARE OF EXPERIMENTAL CONDITIONS

Group	Day			
	1	2	3	4
1, 5	2:1	4:1	3:1	1:1
2, 6	3:1	1:1	4:1	2:1
3, 7	4:1	2:1	1:1	3:1
4, 8	1:1	3:1	2:1	4:1

Note.—Groups 1–4 performed with frequencies of 60–40, while Groups 5–8 performed with frequencies of 80–20.

Each group received instructions only during the first experimental session. At this time, *E* explained that the experiment involved risk taking and gambling and that *Ss* should try to make as much money as possible. The experimental procedure was then explained and *Ss* were able to ask questions until everyone understood. It was further explained that all the chips were worth 1 cent and that everyone would start with 100 chips on each day. Since the total sum of money was paid on the final day, *E* recorded the amount of the chips that each *S* had at the end of each session. Following the instructions, *Ss* were told the particular gain ratio for that day and were informed that they would lose one chip every time that they guessed incorrectly. On the subsequent days, *Ss* were only told the gain ratios before the experimental session began.

The experimental trials were well spaced and *Ss* had considerable time to make their choices. At the beginning of each trial, *E* pressed a control switch. After 12 sec., the buzzer sounded for 3 sec. Three seconds after this, the informing light came on. The *S* would turn on his choice light any time between the onset of the buzzer and the onset of the informing light. The *E* then paid the winners and took one chip from the losers. After paying off, *E* told *Ss* to clear their choice lights, and pressed his control switch to clear the informing lights and initiate the next trial.

Subjects.—The *Ss* consisted of 11 women and 21 men volunteers who had never taken any experiment of this sort. Thirty of these *Ss* were attending the summer school session, and the other two were wives of students.

RESULTS

Figure 1 shows the proportion of times that the light with the higher

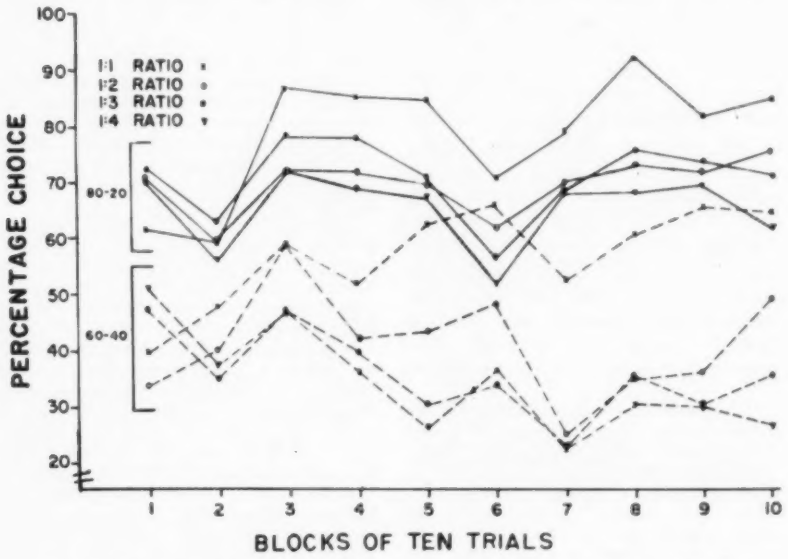

FIG. 1. Percentage choice of the higher frequency light for each block of 10 trials.

percentage of occurrence was chosen, in each block of 10 trials, for each combination of conditions. Each point on the figure represents an average for 16 *Ss*. In interpreting the curves, it is important to consider the following. The Expected Value (EV) is maximized by always predicting the more frequent light for all 80%–20% conditions and for the 60%–40%, 1:1 condition. No optimal solution exists for the 60%–40%, 1:2 condition (since the EV of the two lights are identical). In the remaining two conditions the 40% light should always be chosen.

Consider Fig. 1. The 80%–20%, 1:1 curve fluctuates about the 80% point. There is an increase in percentage choice of the 20% light, as the reward on that side is increased. However, even when that light pays 4 cents, it is still chosen less than 50% of the time. The 60%–40%, 1:1 curve rapidly approaches the 60% point. For the 60%–40%, 1:2 condition the higher frequency light is the less frequently chosen. Again the percentage choice of the less frequent light increases as the reward on it is increased. In the case of the 60%–40%, 1:3 and 1:4 conditions, the less frequent light is chosen more than half the time. In all cases, the light with the higher EV was chosen more than 50% of the time. Furthermore, this preference increased as the difference between the two EVs increased.

Table 2 presents the observed asymptotic percentage choice of the more frequent light (asymptote), asymptotic predictions yielded by two formulas, Expected Gain (EG) and the Relative Expected Loss Minimization (RELM) values obtained by using Edwards' rule. The last 30 trials were averaged in order to obtain the most stable estimate of asymptotic performance available from the limited number of trials run. The EG predictions were obtained in the following manner. The gain on a light was multiplied by the relative frequency of occurrence. This figure was then divided by itself plus a similarly derived figure for the alternative light. For example, if one light appears 80% of the time and pays 1 cent, while the other light appears 20% of the time and pays 2 cents, the EG predictions for the more frequent light would be $(.80)(1)/[(.80)(1)+(.20)(2)]=.6667$. The EG solution gives rather accurate predictions for all 60%–40% groups, the average deviation of asymptote from prediction being 2.33%. This model is much less successful in predicting asymptotes for the 80%–20% groups, the average deviation being 12.16%.

TABLE 2

ASYMPTOTIC ESTIMATES, ASYMPTOTIC PREDICTIONS OF THE EG SOLUTION AND RELM VALUES FOR THE MORE FREQUENT LIGHT

Condition		Asymptotic Estimate	EG Predictions	RELM Values
Percentage	Gain			
60–40	4:1	.28958	.2727	−.500
60–40	3:1	.33958	.3333	−.286
60–40	2:1	.40208	.4286	.000
60–40	1:1	.64375	.6000	.400
80–20	4:1	.67083	.5000	.461
80–20	3:1	.74167	.5717	.667
80–20	2:1	.74375	.6667	.909
80–20	1:1	.86875	.8000	1.200

The RELM value is the ratio of the difference in the expected losses on the two lights to the mean expected loss on the two lights ($\Delta EL/EL$). Loss, a measure first suggested by Savage (1951), is the difference between the obtained result and the payoff which a correct prediction

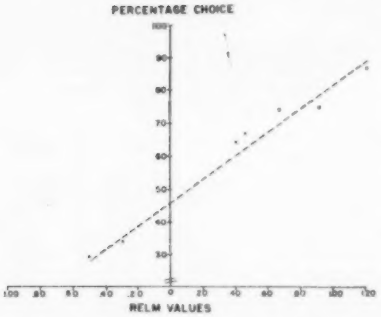

FIG. 2. The least squares line for the relationship between percentage choice of the higher frequency light and the RELM values.

would have yielded. The RELM values in Table 2 yield ordinal predictions and are not asymptotic estimates. Since the data were analyzed in terms of the percentage choice of the more frequent light, a negative value means that this alternative should be chosen less than 50% of the time. The RELM rule predicted perfectly the rank ordering of the eight observed asymptotes. A product moment correlation between these asymptotes and the RELM values yielded an r of .98. The best fitting line (least squares solution) for this relationship had a slope of .359 and an intercept of .459, and is shown in Fig. 2. The standard error of estimate for this relationship was .0435.

DISCUSSION

The data suggest that *S*s can, and do, learn which of two lights is most rewarding over a long series of trials, that they do not form mathematically optimal solutions, and that the closeness of the behavior exhibited to optimal behavior is a function of the gain ratio on the two lights. In all seven conditions in which one of the two lights had a higher EV than the alternative, *S*s learned to choose the higher EV light more than 50% of the time. The closest approximation to 100% choice of the higher EV light (optimal behavior) was exhibited in the 80%–20%, 1:1 condition. In this case asymptotic percentage choice was about 87%. It is doubtful that the preference for the correct light is based upon any mathematical calculations by *S*. In fact, it may be safely assumed that no *S* had the necessary level of mathematical sophistication to arrive at such calculations. It seems more likely that in the course of testing a number of hypotheses (that one or another response pattern is correct, or that the high frequency, or perhaps the high gain, light is most rewarding) over a series of trials, *S* finds most rewarding some hypothesis which necessitates choosing the higher EV light a majority of the time. The percentage of responses to the lower EV light appears to be a function of the relative amounts of reward associated with the two lights. Thus, the preference for the higher EV light decreases as the gain on the alternative increases. If the gain on the higher EV light increases (note 60%–40%, 1:3 and 1:4), the preference for that light increases. In both the 80%–20% and 60%–40% groups, the greatest difference in percentage choice occurs between the 1:1 and 1:2 gain ratios. This result suggests some exponential relationship between percentage choice and gain which is quite in keeping with most theoretical views of the effect of amount of reward upon performance. In considering the preceding discussion it should be kept in mind that running more trials might have led to more stable estimates of asymptote. However, the authors feel that Fig. 1 shows no trends in the last few trials which would suggest that more data would vitiate the conclusions drawn.

EG matching solutions.—The EG solution gave accurate estimates only with the 60%–40% groups. This is consistent with studies which found that when monetary gains are involved, *S*s will get closer to the optimal strategy of always choosing the higher gain light, and further away from a matching solution as the differences in probability

of reward increase (Edwards, 1956; Goodnow, 1955). Data from the present and previous studies suggest that the switch from a matching solution toward an optimal solution occurs in the interval between 60%–40% and 80%–20%.

RELM rule.—This model seems to have some promise for predicting the effects of differential amounts of reward. Edwards, who originally applied and developed this rule, believes that its predictive value results from the fact that RELM values take into account tendencies to prefer high frequency of reward to low, and large gains to small. A third potential advantage is that the rule also takes into account the loss incurred by an incorrect choice. Studies using loss ratios other than 1:1 are necessary to investigate how successfully loss is accounted for.

If the RELM rule only predicted order, it would be of limited interest. The difference between the EVs on the two lights would, for example, do this. However, the rule has certain properties which suggest that it may be useful as a predictor of asymptotic percentage choice. The RELM rule requires that (*a*) *S*s always choose one light over another if the first is always correct and pays more, or if the second light is never correct and pays less; (*b*) that percentage choice varies with the gain ratios rather than with the differences in gain; (*c*) that equal increments in ΔEL yield smaller changes in RELM value as the average EL increases (a reasonable conclusion in the light of psychophysical research); and (*d*) that the closer either relative frequency is to 100%, the more closely *S*'s behavior approximates an optimal solution. Since these requirements are logically consistent with our expectations of behavior in the situation, and since they are consistent with other data (e.g., amount of reward and psychophysical), the RELM model rests upon a firm logical basis. All four requirements can be tested experimentally, and such tests are a necessary part of any research program aimed at validating the model.

What is the empirical evidence for the RELM rule? In two studies, differing in design, procedural details, and game matrices, it has led to a highly accurate prediction of rank order of observed asymptotic percentage choice. In both cases, the RELM value and percentage choice were highly correlated. Observations showed little scatter about a least squares regression line. The standard error of estimate was .056 for Edwards' data,[3] .043 for our own. The two slope coefficients were .287 (Edwards) and .359 (present study), both greater than .250, a theoretically minimal value occurring only when *S* requires a 100%–0% event distribution in order to reach optimal solution. Edwards' slope-intercept of .638 indicates a position preference, but our obtained value of .459 is further support for the rule. The slope-intercept should be near .500 since at this point $\Delta EL = 0$, and no preference should exist.

Linearity of regression, and the compatibility of obtained slope and slope-intercept values with theoretical ones suggest that the model may be utilized to obtain predictions of asymptotic percentage choice. However, much more is needed to validate the RELM rule. A number of studies, varying only in the payoff matrices, are required to obtain estimates of sample-to-sample fluctuations of the regression parameters. Assuming that a linear relationship exists, and that stable estimates of the linear parameters can be obtained, the relation of these parameters, particularly the slope, to various variables must be explored. For example, Edwards has suggested that the slope should increase with increases in motivation up to a certain point, and then decrease. It also remains to be determined whether or not the RELM formula is generalizable to game matrices which differ qualitatively from those investigated in this study. Two examples are the cases of independent lights (both, either, or

[3] All referenoes to Edwards' data in this study are derived from asymptotic estimations based on the last 50 trials for the OL and OD (only one light correct on each trial, as in this study) groups in Fig. 3 of his paper.

neither light may be correct on a given trial) and of differential costs. No data exist for the latter, and Edwards' results for the former are far less satisfactory than for the nonindependent condition. The RELM rule holds some promise but the vast bulk of research relating to it remains to be done.

Summary

The present experiment was designed to study the effects of differential monetary rewards in a two-light guessing game. A further purpose was to examine the various quantitative models which might be utilized to predict *Ss*' asymptotic response frequencies. The results and conclusions were:

1. Although *Ss* do not form mathematically optimal solutions, they do learn to choose the most rewarding alternative a majority of the time. The observed response frequencies appear to be a function of both the frequencies of reward and the relative amounts of reward.

2. A model using estimates derived from expected gains did not adequately predict asymptotes over a wide range of experimental conditions. A second model based on the concept of expected loss seems to be a promising solution for the prediction of asymptotes. Although this model does have a logical basis, and supportive data, considerable research is needed to validate its use.

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PREDICTING INSTRUMENTAL PERFORMANCE FROM THE INDEPENDENT RATE OF THE CONTINGENT RESPONSE [1]

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This experiment was designed to test part of a theory of positive reinforcement (Premack, 1959). The theory distinguishes between the noncontingency and contingency situations, and the two rates of responding measured in these situations which are called independent and dependent rate, respectively. The defining property of the noncontingency situation is the absence of a conditional relation between presence of test item and *S* responses. In the simplest such situation the test item is present throughout the session, as when a bar or a drinking tube is contained in the same experimental space with *S*. But presence of test item throughout the session is not a defining property; the item may be alternately removed and restored so long as its presence is not conditional upon *S* responses. The contingency situation, in contrast, is defined by a conditional relation between presence of test item and *S* responses, as when the drinking tube is present only if *S* has pressed a bar, or the bar is present only if *S* has drunk from the tube. The theory is concerned with both situations for it represents an attempt to predict dependent rate from independent rates; that is, to account for contingency properties from measures taken in the noncontingency situation.

[1] This study was begun during the author's tenure as a USPHS postdoctoral research fellow and completed with the support of Grant M-3345 from the National Institute of Mental Health. The author is indebted to Z. Pace for assistance in collecting the data.

The theory consists of two assumptions. First, if the responses of an individual are ranked in terms of their independent rates, the higher member of any pair of responses, when made contingent upon the lower member, will reinforce the lower member.[2] Second, the increment given the lower-rate response is proportional to the independent rate of the contingent response. These assumptions are then generalized by further assuming that independent rates of like numerical value are of like reinforcement value, irrespective of the responses in which the rate is manifested or the parameters with which the rate is obtained.

[2] This main assumption of the theory presupposes a scale on which there can be ranked all the responses of an individual or species that have the property independent rate. This, in turn, presupposes a specific definition of "response," for while the function that is entailed by the first assumption need not hold for all response definitions, a definition for which it does hold must be shown. Quite probably this definition will differ from current response definitions for these were generated by systems where response occurs only as dependent variable, unlike the present case where it occurs also as independent variable, and, criteria for the dependent variable permit arbitrariness impermissible in the independent variable. No direct contribution is made by the present experiment to this problem for the response units that its uses are of the arbitrary, dependent-variable type. Nevertheless, if use of conventional response units continues to confirm the first assumption, confidence may reasonably grow that a response unit rule exists and will be found. A suggestive though wholly inadequate first attempt to solve this problem may be found elsewhere (Premack, 1959).

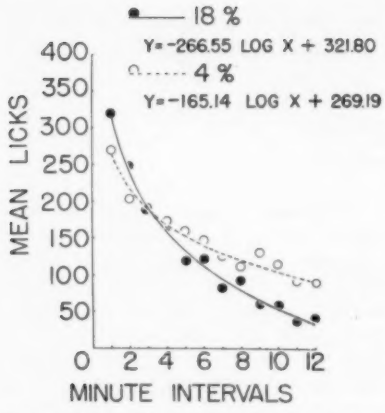

FIG. 1. Mean lick rate as a function of time.

The manner in which the assumptions were tested in the present experiment may be shown by referring to Fig. 1 which presents the mean independent lick rate per minute for two groups of rats, one receiving 18% sucrose, the other 4%. Given a response whose independent rate is less than that of the lick rates, such as the bar press in the rat, the assumptions can be tested by associating certain of the lick rates with the bar press and then determining whether dependent bar press rate reflects the associated independent lick rate.

The association of different independent lick rates with the bar press is accomplished by a two-stage procedure in which *S* first licks from a drinking tube and is then transferred to a Skinner box where each bar press produces the previously licked solution. In the present case, each of four groups of rats was allowed to lick from a drinking tube either 4% or 18% solution for either 30 sec. or 8 min. before being placed in the Skinner box. Since, as is shown in Fig. 1, the 18% and 4% lick rate curves cross at about the third minute, the pairs of values corresponding to 30 sec. and 8 min., respectively, are such that the concentration-lick rate relation at 30 sec. is the reverse of that at 8 min. Thus, associating the above lick rate values with the bar press provides this main check on the theory: for *S*s given only 30 sec. prelicking before being placed in the Skinner box, the 18% solution should produce the higher initial bar press rate, whereas for *S*s given 8 min. prelicking the concentration-reinforcement relation should be the reverse, and the 4% solution should produce the higher initial bar press rate.

METHOD

Subjects.—The *S*s were 24 female rats, ca. 90 days old, of the Sprague-Dawley strain. They were housed individually, and maintained on a 1½ hr. daily feeding schedule instated 14 days before the experiment began.

Apparatus.—Drinkometers and Skinner boxes were used. The former consisted of a set of four adjoining boxes, each with a hole in the rear wall into which a drinking tube was inserted. The boxes were 7 × 7 × 9½ in., built of wood except for hardware cloth floor and rear wall, and were painted flat black on all wood sides. Drinking tubes were modified 50-ml. burettes, with apertures of about 6-mm. inner diameter. A circuit connected to each tube was so arranged that each time *S*'s tongue contacted the fluid a minute current passed through *S*'s body, activating a counter. Counter readings were taken at 1-min. intervals.

Four Skinner boxes equipped with dipper-type magazines were used. T-shaped bars, 1½ in. along the horizontal, were mounted 4 in. above the test cage floor, and extended about 1½ in. into the cage. The bars were activated by about 22-gm. force. Test cages were Hoeltge HB-11A rat cages, the same as those used for housing *S*. A small hole in the cage floor directly beneath the bar admitted the dipper. In the first of the two studies to be reported here, the inner diameter of the dipper was about 8.5 mm., as close to drinking-tube aperture as could be arranged; in the second study, dipper diameter was only 3.5 mm. The entire test assemblies were mounted in 16 × 21 × 36 in. sound-deadened, ventilated, icebox hulls. Drinkometers and Skinner boxes were in close propinquity, permitting *S* to be moved from the former to the latter in about 10 sec.

The two solutions used, 18% and 4% sucrose by weight, were prepared, on alternate days, from commercial granulated sugar and distilled water.

Procedure.—Drinking: The *S*s were randomly assigned to either the 18% or 4% sucrose and given 14 daily sessions in the drinkometers in the order listed: four 3-min., four 6-min., and six 12-min. sessions. Both main concentration groups were then subdivided, with mean lick frequency averaged over the last six sessions as the matching variable. The four groups thus formed are referred to hereafter as: 18-S, 18-L, 4-S,

4-L. S (short) and L (long) refer to the length of time *S* was subsequently left in the drinkometer before being transferred to the Skinner box; S and L were 30 sec. and 8 min., respectively.

Bar pressing.—On Day 15, bar press training was begun. General procedure was the same for all groups: *S* was placed in the drinkometer for either 30 sec. or 8 min. and then transferred immediately to the Skinner box. This same predrinking procedure was used for both magazine and bar press sessions, but was not used during extinction when, instead, all *Ss* were transferred directly from home cage to Skinner box. All groups were given four magazine, six bar press, and four extinction sessions, the sessions lasting 12 min., 15 min., and 24 min., respectively. Forty-eight dipper operations, at a mean interval of ½ min., were given per magazine session. A continuous reinforcement schedule was used during bar press sessions. The dippers were preloaded during both magazine and bar press sessions, so that when *S* was transferred from drinkometer to Skinner box, it could resume licking immediately. The *Ss* were run in squads of four, each squad containing two *Ss* from each concentration condition, with the S and L conditions being alternated between squads. Concentrations were counterbalanced across Skinner boxes, but each *S* was always tested in the same box.

A second study using the same groups was run immediately after the first. Procedure was identical except for the use of the small rather than large dippers, and a 24-min. (rather than 15-min.) bar press session. Results for the two studies are presented separately below.

Results

Drinking.—The rate of licking for the 18% and 4% solutions as a function of time in the test apparatus is shown in Fig. 1. Each point represents the mean number of licks made per minute by 12 *Ss* averaged over the last six 12-min. sessions. The curves are the least squares fit to log time; a test of the goodness of fit was made for both curves by analysis of variance (Lewis, 1949, pp. 281–284), and the hypothesis of goodness of fit was not rejected, since in both cases $F < 1.00$.

To determine whether the group curves in Fig. 1 were representative of the individual curves, a separate plot was made for each of the 24 *Ss* of number of licks per minute summed across the last six 12-min. sessions. Five of the individual curves differed grossly from the group curves: two did not decline across the 12-min. session, suggesting the need for a longer session, while three others showed no evident systematic relation between lick frequency and time in test apparatus. The remaining 19 individual curves appeared to be adequately represented by the group curves, in the sense that they would be reasonably well fitted by negatively accelerated log or exponential functions. The five deviant *Ss* were not removed from the sample, as this would have both disturbed counterbalancing between treatments and apparatus and further reduced the small *Ns*, and all statistical tests are for the entire sample.

The inversion between lick rates may be seen to occur at about the third minute, the 18% group being consistently higher prior to that point, the 4% consistently higher thereafter. The data were analyzed for Concentration and Intrasession Interval (by 1-min. interval), and a significant interaction between Concentration and Interval was obtained, indicating significant slope differences ($F = 3.64$, $df = 11/242$, $P < .01$). Inspection of the data revealed considerable session-to-session variability; in five of the six sessions, the inversion occurred between the second and fifth minute, but it did not occur in one session until the eighth minute. However, in all sessions once the inversion in mean lick rate occurred, there were no subsequent reversals.

Bar pressing.—Figure 2 shows the mean log bar press frequency per

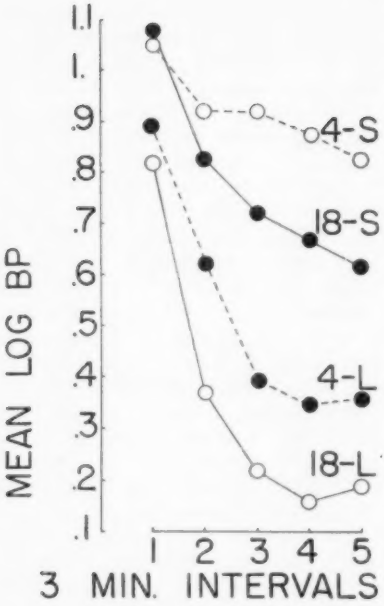

FIG. 2. Acquisition of bar pressing as a function of time with sucrose concentration and prelick interval as parameters.

3-min. interval averaged over all six bar press sessions. The notable feature here is the agreement between the ordinal relations of the four bar press curves and the appropriate corresponding values of the lick rate curves. (*a*) As is predictable from comparing the values of the lick rate curves from the first minute on with the values from the eighth minute on, both 30-sec. contingency groups (18-S and 4-S) were consistently higher than both 8-min. contingency groups. (*b*) When the contingency between the bar press and licking occurred prior to the inversion in lick rates, the 18% group (18-S) had a higher *initial* rate than the 4% group, whereas when the contingency occurred after the inversion in lick rates, the 4% group (4-L) had the higher initial rate.

An analysis of variance for S-L Condition, Concentration, and Intrasession Interval (by 3-min. intervals) showed that the group differences were accounted for largely by the S-L Condition ($F = 31.17, df = 1/20, P < .001$), and that Concentration effects were also significant ($F = 4.49, df = 1/20, P < .05$). The significance of the concentration effect resulted from the overall superiority of the 4% groups.

Extinction.—Figure 3 shows the mean log bar press frequency per 3-min. interval averaged over all four extinction sessions. The combined 30-sec. contingency groups (18-S and 4-S) were significantly higher than the 8-min. contingency groups ($F = 31.17, df = 1/20, P < .001$). Concentration, on the other hand, did not significantly affect extinction as it did acquisition ($F < 1.00$), nor did the S-L × Concentration interaction attain the 5% level. However, as may be seen in Fig. 3, the *initial* extinction rates were ordered

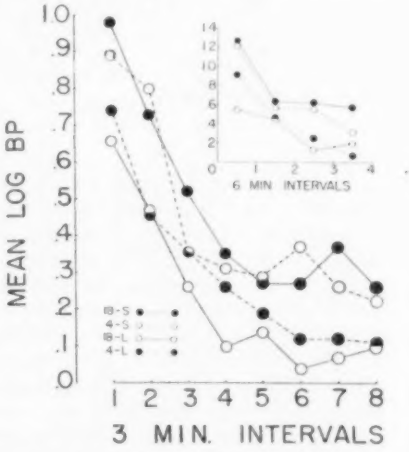

FIG. 3. Extinction of bar pressing averaged over all sessions, and first session of bar pressing (insert) as a function of time with training sucrose concentration, and training prelick interval as parameters.

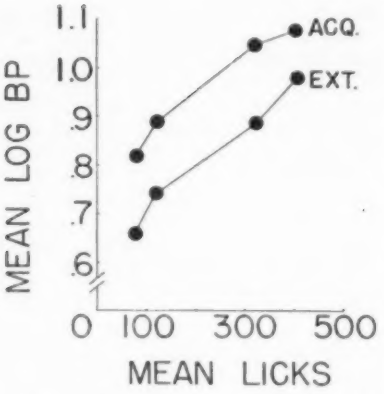

FIG. 4. Initial 3 min. of acquisition and extinction bar pressing as a function of the highest mean lick rate associated with the bar press.

the same as the initial acquisition rates. Initial extinction responding should provide the more sensitive index of group differences, since differences between the groups decrease with repeated extinction testing. An analysis of variance for S-L Condition and Concentration in the first 3 min. of responding showed the S-L × Concentration interaction to be highly significant ($F = 13.59$, $df = 1/20$, $P < .001$).

The results for the first session only, plotted by 6-min. intervals, are shown in the smaller figure in the upper corner of Fig. 3. An analysis of variance on these data for S-L Condition, Concentration, and Intrasession Interval (by 6-min. intervals) showed that only the effect of the S-L Condition was significant ($F = 33.58$, $df = 1/20$, $P < .001$). Although the S-L × Concentration interaction did not attain the 5% level ($F = 1.76$, $df = 1/20$, $P = .20$), the suggested separation between the four groups is more evident in the data for the first extinction session only.

The relation between bar pressing and lick rate is further shown in Fig. 4. The first 3 min. of both acquisition and extinction responding are plotted as a function of the *highest* mean lick rate—the lick rate values being taken from the fitted curves—that was associated with the bar press for each of the four groups. The lowest lick rate for which bar press values are plotted represents the highest mean lick rate that was associated with the bar press in the case of Group 18-L; the remaining values, in ascending order, are those for Groups 4-L, 4-S, and 18-S, respectively. As may be seen, both bar press rates vary directly with the highest mean lick rate that was associated with the bar press.

Small dipper.—Figure 5 shows the mean log frequency of bar pressing per 3-min. interval averaged over the six sessions given with the small dipper. Aside from reducing the slopes of the curves, the main difference produced by the small dipper concerned the 30-sec. contingency groups. In contrast to the large-dipper case, Groups 18-S and 4-S did not cross, but rather, 18-S began and remained higher than 4-S throughout the session. Statistically, this differ-

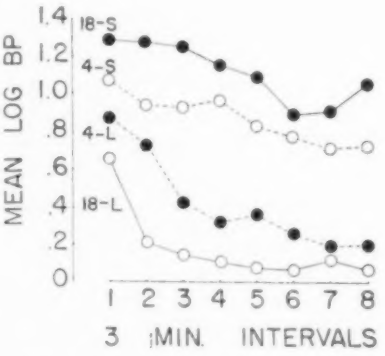

FIG. 5. Acquisition of bar pressing as a function of time with sucrose concentration and prelick interval as parameters; small dipper used in training.

ence is reflected in the fact that the S-L × Concentration interaction was significant ($F = 11.96$, $df = 1/20$, $P < .005$); also, unlike the large-dipper case, concentration per se did not significantly affect responding ($F < 1.00$). These results suggest that size of the drinking aperture may affect the independent rate of licking; specifically, that with a "small" aperture the inversion in lick rates for the two solutions may occur substantially later than with a "large" aperture.

The extinction results for the small dipper were essentially the same as those for the large dipper, and are not shown here. The combined 30-sec. contingency groups were significantly higher than the 8-min. contingency groups ($F=31.17$, $df=1/20$, $P < .001$), while neither the effect of Concentration nor that of the S-L × Concentration interaction approached the 5% level. As in the case of the large dipper, the initial extinction rates were ordered the same as the initial acquisition rates; and an analysis of variance for S-L Condition and Concentration in the first 3 min. of responding showed the S-L × Concentration interaction to be significant ($F = 14.35$, $df = 1/20$, $P < .001$).

Discussion

Although use of the consummatory response as reinforcing event contributes little to the assumption that a rate differential is a sufficient condition for reinforcement, the response is convenient for testing the second assumption. In order to determine whether the increment to the lower-rate response is proportional to the independent rate of the contingent response, a series of independent rate values is needed. The series is directly arranged in the case of the consummatory response for there parameters of independent rate are known. However, in less traditional cases, for example manipulation, there are no known parameters comparable to, say, sucrose concentration, and consequently arranging a series of independent rates requires a trial-and-error procedure wherein rates are "found" rather than produced. In view of the use of the traditional consummatory response, this experiment was directed mainly at the proportionality assumption, though confirmation of the first assumption depends in any event upon piling up cases.

The data provide three separate, though not independent, ways in which to examine the proportionality between dependent bar press rate and associated independent lick rate. These concern: initial rate, frequency for the session, and slope of the curves.

Initial rate.—The initial and also the highest lick rates associated with the bar press in each of the four groups were the pairs of values corresponding to 30 sec. and 8 min., respectively, in the fitted curves in Fig. 1. These values should be reflected in the order of the initial bar press rates of the four groups; that they were is shown in Fig. 4 where it may be seen that bar pressing in the first 3 min. varied directly with the initial and highest lick rates associated with the bar press. These data contribute to the assumption that, as concerns reinforcement, rate is indifferent to the obtaining parameters, for whether variations in lick rate were produced by variations of concentration or of prelick interval, bar press order was predictable from lick rate order. Moreover, since in the 30-sec. condition 18% produced the higher initial bar press rate, while in the 8-min. condition 4% produced the higher initial bar press rate, sucrose concentration would seem to be less a direct parameter of reinforcement than a determinant of independent lick rate. Though representing only one piece of evidence in the host that is needed, the data support a main implication of the theory: independent rate has many parameters, but dependent rate has only one—the difference

between the independent rates of the associated responses.

Total bar presses per session.—Since initial bar press order was predictable from initial lick rates, it may be possible to make the same type prediction for any interval and therefore, by summing over the intervals that make up the session, to predict order for bar presses per session from licks for the session. To predict order for the four groups in terms of mean total number of bar presses per session, we require the mean total number of licks predicted to occur in the bar press session for each of the four groups, and this may be determined by integrating the lick rate functions for the appropriate intervals.[3] For the interval .5 to 15.5 min., which is appropriate for both S-groups, the values for 18-S and 4-S were 1604 and 2041, respectively; for the interval 8 to 23 min., which is appropriate for L-groups, the values for 18-L and 4-L were 290 and 1133, respectively. Thus, in terms of mean total licks predicted for the period in which bar pressing and licking were associated, the order of the groups, in ascending fashion, was 18-L, 4-L, 18-S, and 4-S; this was also the order of the groups in terms of mean total bar presses per session. These differences did not attain the 5% level, though combining scores for the concentration condition and for the prelicking condition permits examining essentially the same prediction in terms of main effects, rather than their interaction, and differences for main effects were significant. Thus, mean total predicted licks for combined 4% and combined 18% groups were 3174 and 1894, respectively, and corresponding scores for combined 30-sec. and combined 8-min. groups were 3645 and 1423, respectively. These differences should be, and were, reflected in main bar press effects: combined 4% groups made significantly more bar presses per session than combined 18% groups; similarly, combined 30-sec. groups made significantly more than combined 8-min. groups. It would appear possible, therefore, to predict ordinal dependent rates from associated independent rates for the total session as well as for the initial interval of the session.

Slope.—Since, as shown in Fig. 1, the change in rate of licking over the interval 1 to 12 min. was notably greater than over the interval 8 to 12 min., slope of the bar press curves for S-groups should be notably greater than for L-groups. That is, in L-groups bar pressing and licking were not associated until after the main decrement in lick rate had occurred, and therefore, in L-groups slope changes in bar pressing should be relatively small; on the other hand, in S-groups the period of association between bar pressing and licking includes the main change in lick rate, and therefore, in these groups slope of the bar press curves should be relatively great. However, as may be seen in Fig. 2, the opposite held: slope for L-groups being notably greater than slope for S-groups.

It is not possible from the present theory to determine for which condition the slopes are "improper"; S slopes may be proper and L slopes too great, or vice versa, or both may be improper.

Two factors may possibly account for the failure to obtain the predicted outcome. (*a*) Initial points for L groups may be "too high"; if *S* failed to resume licking immediately when moved from drinkometer to Skinner box, a recovery in lick rate might then occur, in which

[3] Although the curves in Fig. 1 fit the empirical points better than all others that were tried, they lead to unreasonable terminal values, and therefore present difficulties when the integration involves extrapolating beyond the points to which the curves were fitted. The 4% curve stabilizes at too great a value; consequently the estimation for 4-L is inflated. The 18% curve takes on negative values after Minute 16. Here the solution used was to carry integration only to Minute 16. However, in no case were the problems of extrapolation serious for the predictions made by the theory. Although the extrapolated values involve error, ordinal relations of the four groups are identical whether lick totals are calculated to Minute 23, which involves extrapolation, or only to Minute 12, which is the limit of the empirical points.

case actual initial lick rates associated with the bar press would be higher than predicted by the 8-min. interval of the fitted curves. Some evidence for this can be found in Fig. 2 for 18-L, though not for 4-L. If, for the sake of comparison, differences between tube and dipper presentations of sucrose solutions are ignored, then L and S groups will have had approximately equal exposure times to the solutions by Minutes 3 and 10.5 of the bar press sessions, respectively (8 tube plus 3 dipper, L groups *vs.* .5 tube plus 10.5 dipper, S groups). Accordingly, L-group bar press values in Minute 3 should agree with S-groups values in Minute 10.5. In fact, 4-L and 4-S agree well, but 18-L would appear sufficiently higher than 18-S to suggest an elevation in the initial value for 18-L. (*b*) Apart from, and more important than, discrepancies in initial values, the subsequent rate of decline in bar pressing for L-groups may be considered substantially greater than would be predicted by theory from the slope of the S-group curves. Here common sense might consider that an *S* containing 8 min. worth of sucrose solution will not bar press for additional solution in an amount equal to that which it will lick freely. But no such prediction follows from this theory, and to clarify this point will require comparing amount *S* drinks, or number of licks *S* makes, from Minute 8 to Minute 15 in drinkometer and Skinner box, respectively.

Extinction.—Since the theory does not contain a nonreinforcement postulate and, more important, does not treat *negative* reinforcement which, more than nonreinforcement per se, may be responsible for extinction, formal extinction predictions cannot be drawn from the theory. Nonetheless, the data are of intrinsic interest, and also, they may prove useful in devising an extinction account that is in keeping with the rest of the theory. There were two main extinction outcomes: (*a*) combined S-groups made significantly more extinction responses than combined L-groups, and (*b*) overall initial extinction rates differed significantly for the four groups.

Superiority of S over L groups is not an especially instructive finding, being explicable by either of two factors. (*a*) The S-groups received significantly more reinforcements than L-groups, and (*b*) since all groups were extinguished without any prelicking, and this more resembles the 30-sec. than 8-min. training condition, differences between training and extinction conditions may be considered to have favored S-groups.

Initial extinction rates, however, prove to be instructive for, while the S-L difference is readily accounted for, neither *N*-reinforcements nor the training-extinction difference will account for the initial extinction differences. For example, 18-S received fewer reinforcements than 4-S, and yet had a higher initial extinction rate; similarly, though the training-extinction difference may have favored both S groups, it is a two-way difference and as such will not account for a four-way difference in initial extinction rates.

In terms suggested by the present theory, there are three logically possible alternatives by which to account for the initial extinction differences. These alternatives arise in the first place because in all four groups the bar press was associated not with one value of the higher-rate response but with several. That is, from combined consideration of Fig. 1, the bar press performance results, and the rest of the theory, it it may be reasonably inferred that lick rate per time interval, or instantaneous lick rate, decreased throughout the interval in which bar pressing and licking were associated, thereby resulting in the association of a number of lick rates with the bar press. This represents a more complex state of affairs than is envisaged by the original proportionality assumption, which says merely that dependent rate is proportional to associated independent rate and which, as such, is an adequate specification only for the simplest case, viz., where the higher-rate response is associated at

only one value. Since, however, here and in free-responding experiments generally, rate of the higher-rate response may be expected to change over the contingency interval—with the resulting association of more than one value of the higher- with the lower-rate response—some extension of the original proportionality assumption is needed in order to deal with this more complex case.

The principal logical alternatives are that initial extinction rates are proportional to (*a*) highest associated instantaneous rate of the contingent response, (*b*) lowest associated instantaneous rate, or (*c*) mean of the several associated rates.

The present data are compatible only with the first alternative. As shown in Fig. 4, initial extinction rates varied directly with the *highest* of the several associated rates. In contrast, both mean-lick rate and lowest-lick rate predict only that which the original proportionality assumption requires they predict: ordinal mean lick-contingent bar presses per session, and order of the four groups as to lowest lick-contingent bar press rate attained, respectively. The success of these measures confirms that ordinal dependent rate can be predicted for *any* interval from independent rate for the corresponding interval. But the extinction data would nonetheless seem to require this additional assumption: if *several* values of the same higher-rate response are associated with a lower-rate response, then, other things equal, the increment to the latter will be proportional to the *highest* of the several values. Whether the original proportionality assumption needs to, or can, be reformulated so as to include this case, or whether the two must stand as separate assumptions, can be established only by further data.

Summary

This study was designed to test part of a theory of positive reinforcement for which main assumptions are the following: (*a*) a difference in independent rates of referent and contingent responses is a sufficient condition for reinforcement, (*b*) the increment to the referent response is proportional to the independent rate of the contingent response, and (*c*) independent rates of like numerical value are of like reinforcement value though the rates are obtained with different parameters.

Using bar pressing and licking as referent and contingent responses, respectively, the study proceeded as follows: Different lick rates were associated with the bar press by a two-stage procedure in which each of four groups of rats ($N = 6$) was, first, allowed to lick from a drinking tube either 18% or 4% sucrose for either 30 sec. or 8 min., and second, was transferred to a Skinner box where each bar press produced the previously licked solution. Two studies were run involving the same groups in which dipper and drinking tube apertures were and were not of the same size. After bar press training all groups were extinguished with no prelicking.

Results and theory conformed as follows: (*a*) When dipper and drinking-tube apertures were comparable, ordinal bar press rates for the session, and for the initial and terminal intervals of the session, were predictable from independent lick rates for the corresponding intervals. (*b*) Bar press order was predictable from lick rate order whether a given lick rate was produced by sucrose concentration or by prelick interval. (*c*) Differences between drinking-tube and dipper apertures produced some disagreement between ordinal relations for the bar press and lick rate curves, suggesting that size of the dispenser aperture may be a parameter of independent lick rate. (*d*) Initial extinction rates varied directly with the highest lick rate associated with the bar press, suggesting the need for this additional assumption: if more than one value of a higher-rate response is associated with a lower-rate response, the increment to the latter will be proportional to the highest of the several values.

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SPEED OF RUNNING IN EXTINCTION AS A FUNCTION OF DIFFERENTIAL GOAL BOX RETENTION TIME[1]

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The effect of prolonged goal box confinement during extinction on the rate of extinction of a maze running response has produced conflicting results. Bugelski, Coyer, and Rogers (1952) found no difference in rate of extinction between groups confined 20 sec. and 120 sec. They used an elevated runway.

Stanley and Rowe (1954) confined groups in the goal box of an alley maze for 10 sec., 30 sec., and 60 sec. at the end of each extinction trial. The 60-sec. group was least resistant to extinction, the 30-sec. group next and the 10-sec. group most resistant, but only the extreme groups were significantly different. These data were interpreted within a contiguity framework as follows: the longer *S* is confined, the more responses will be made which are incompatible with running in the alley of the maze; these responses, such as defecating, "freezing," and scratching at the door, should tend to move forward in time and disrupt the running response.

An analysis of the situation from a secondary reinforcement viewpoint, a possibility implied by Bugelski et al. (1952) and suggested for some latent extinction studies by Moltz (1957), leads to the same general predictions that Stanley and Rowe derived using contiguity theory. The stimuli of the goal box interior should acquire secondary reinforcing properties as a result of immediately preceding a primary reinforcing stimulus during acquisition training. During extinction these secondary reinforcing stimuli (S^r's) should appreciably assist in maintaining response strength. However, if *S*s are confined in the goal box at the end of each trial during extinction, the S^r's of the goal box interior should differentially extinguish as a function of the length of time *S* is in contact with them. Thus if different *S*s are confined in the goal box for 3 sec., 30 sec., 240 sec., and 720 sec. at the end of each extinction trial, the response strength during extinction should be greatest for the 3-sec. group and progressively decline to the 720-sec. group. If other *S*s are made to run only to the closed goal box door and then removed immediately, the S^r's of the goal box interior cannot operate to maintain response strength. These *S*s should represent the limiting case, and be least resistant to extinction.

The position of this last group in a contiguity framework is ambiguous. One might follow Stanley and Rowe and predict increased resistance to extinction since the animals are removed quickly and have less time to make competing responses. On the other hand the cues of the goal box, which should elicit running, are not available.

The purpose of the following experiments is to determine if the predictions from the secondary reinforcement position can be verified.

[1] The author wishes to express his appreciation to Robert Cotter, undergraduate psychology major, for his assistance in the collecting and processing of these data. This investigation was supported by a PHS Research Grant M-3275 from the National Institute of Health, United States Public Health Service.

Experiment I

Method

Subjects.—The *Ss* were 90 naive male albino rats weighing 140–160 gm. at the beginning of the study.

Apparatus.—A straight alley maze was constructed of ¼-in. plywood with interior dimensions of 84 in. long by 5 in. wide and 6 in. deep. Guillotine plywood doors 12 in. from either end separated a start and a goal box from the stem of the maze. Two additional guillotine doors were hung 24 in. and 48 in. from the exit door of the starting box. These constituted nonretrace doors during acquisition and the second door provided one end of a pre-goal box enclosure for the extinction procedures. The end boxes were covered by hinged plywood lids. The room was illuminated solely by a 40 w., 47 in. neon bulb hung 52 in. directly above and parallel to the floor of the maze. A water bottle with metal drinking tube was wired to the exterior of the goal box, the tube projecting through a hole in the far end of the goal box wall. The drinking apparatus was exactly the same as that used to provide *Ss* with water in their home cages. The start box was painted flat white, the alley flat grey, and the goal box flat black. Three replicas of the goal box section of the maze were used for pretraining purposes.

Procedure.—All *Ss* were given 7 days of adaptation to living cages after arriving in the laboratory. During this time they were divided into five experimental groups of 18 *Ss* each and placed on an ad lib. food and watering schedule. The following 4 days all *Ss* were placed on a 23-hr. water deprivation schedule, food continuing ad lib. All acquisition and extinction was carried out under 22-hr. water deprivation. On Day 12 each *S* was placed, when 22-hr. deprived, in a goal box replica with full water bottle attached and retained there for 30 sec. after drinking began.

On Day 13 acquisition training began. All *Ss* were given two trials in the maze and retained in the goal box on each trial for 15 sec. after drinking began. For the following 6 days each *S* was given three trials per day. Each *S* was retained in the goal box for 15 sec. after the initiation of drinking behavior. Running time from lifting start box gate to closing goal box gate was recorded for each trial. Guillotine doors were used to prevent retracing. The three daily trials were approximately 90 sec. apart. By the end of 20 acquisition trials the running times appeared to be approaching a minimum value so the extinction procedures were begun. During extinction, Groups 3, 30, 240, and 720 were retained in the goal box for 3, 30, 240 and 720 sec., respectively, and Group 0 ran to the closed goal box door where the pre-goal box guillotine door was dropped and *S* immediately removed from this compartment. Running time for all groups was taken from raising the start box door until *S*'s body passed the pre-goal box door. The *Ss* were given only one extinction trial per day, to allow for the dissipation of any frustration-produced drive. They were then returned directly to the living cage. Extinction trials continued for 14 days.

Results

Acquisition results.—The daily running times for all *Ss* were given a log transformation because of the obviously skewed distribution. The log running times were then summed for each *S* over Acquisition Trials 12 through 20. A distribution of these sums for all *Ss* was found not to depart significantly from a normal distribution ($\chi^2 = 3.70$, $df = 4$, $.30 < P < .50$). Bartlett's test for homogeneity of variance of the Groups 0 through 720 gave no evidence of heterogenous variances ($B^1 = 1.55$, $df = 4$, $.80 < P < .90$). A between-groups vs. within-groups analysis of variance produced an F of .04. Therefore, at the beginning of extinction there is no basis for rejecting the hypothesis of equivalent groups.

Extinction results.—Although the extinction running time was again skewed, a log transformation of the data resulted in a distribution which did not depart significantly from normal ($\chi^2 = 1.18$, $df = 4$, $.80 < P < .90$). A measure of response strength during extinction for each *S* was obtained by transforming each day's running time to a common logarithm, and finding the mean of this distribution of logs for each *S* over the 13 trials during which the confinement periods

TABLE 1

MEAN LOG RUNNING TIME (SEC.) BY DAYS IN EXP. I

Group	Days														Mean
	0*	1	2	3	4	5	6	7	8	9	10	11	12	13	
0	.47	.94	1.08	1.00	1.09	1.15	1.28	1.22	1.38	1.37	1.28	1.57	1.63	1.55	1.27
3	.55	.70	.64	.72	.70	.85	.91	.86	.81	.91	.82	.95	1.24	1.13	.86
30	.52	.60	.53	.52	.56	.79	.82	.94	.93	.91	.97	.99	1.00	.85	.80
240	.45	.64	.73	.70	.64	.80	.93	.96	.92	1.13	1.05	1.28	1.11	1.08	.92
720	.48	.87	.72	.76	.94	.99	1.07	1.03	1.32	1.26	1.27	1.36	1.31	1.31	1.09

* Mean of four trials preceding introduction of the independent variable.

could have affected running time. The first extinction day is not included as the confinement at the end of the run could not affect that day's running time.

A simple analysis of variance for all five groups yielded an F of 17, $df = 4/85$, $P < .01$. With Group 0 removed, the analysis yielded an F of 7, $df = 3/68$, $P < .01$. The second analysis is evidence that the significance level of the first is not entirely due to the presence of Group 0 and indicates different response strengths during extinction of those groups admitted to the goal box.

Table 1 shows the mean log running time by days for each group and the mean for each group over the 13 day period. The following t's between these group means were obtained: 3 and 30, $t = .96$, $P > .05$; 30 and 240, $t = 1.82$, $P > .05$; 240 and 720, $t = 2.57$, $P < .05$; 720 and 0, $t = 2.69$, $P < .01$. Each t has 85 df since a pooled estimate of within-group variance (Guilford, 1956, p. 264) is used as the error term.

Of the four group comparisons, three are in the predicted direction. Two of these are significant and one falls just short of significance.

Discussion

The predictions from the application of secondary reinforcement theory are confirmed for the following comparisons: Group 0, stopped short of the goal box, is significantly slower than Group 720 which is admitted to the goal box but retained there 12 min. on each trial. Group 720, retained 12 min., is again significantly slower than Group 240, retained 4 min.; and Group 240 is slower than Group 30, retained 30 sec. One prediction is not verified. Group 3 is not significantly different from Group 30. Table 1 shows the stability of these relationships over days. The nonmonotonic function produced by the reversal of Groups 3 and 30 led to a re-examination of the theoretical mechanism operating in the very short retention intervals. Apparently for a short retention time in the goal box, something does not take place which for slightly longer retention times operates to produce additional reinforcement, and consequently keeps running time lower. Note that the mean running time for Group 3 is longer than for Group 30. It may be that *Ss* quickly removed from the box at the end of a run do not have time to complete the chain of behaviors terminating at the drinking tube. If we hypothesize that the 30-sec. *Ss* can complete this chain and the 3-sec. *Ss* have insufficient time, then with this more molecular level of analysis, secondary reinforcement theory would predict a nonmonotonic relationship. The stimuli involved in drinking from the tube should be the most reinforcing by the same logic which led us to predict that stimuli within the box would be more

reinforcing than stimuli within the stem of the maze. This prediction does not affect what happens for long retention periods. Groups 30, 240, and 720 would still extinguish as a function of length of time in the goal box. The modified hypothesis which generates the nonmonotonic prediction was tested in the following study.

Experiment IA

Method

The animals of Group O, described in the preceding study, were utilized in this study. The apparatus was the same as that of Exp. I. Group 0 *Ss* were matched into two groups of nine each on the basis of their mean log running times over the last four extinction days of Exp. I. These *Ss* had had no goal box experience in the maze since acquisition. The *Ss* of Group 0_1 were allowed to enter the goal box and were removed within 1 sec. Those of Group 0_{30} were allowed to enter the goal box and were removed after 30 sec. This procedure was continued for five days, including the initial day's run during which the independent variable could not have produced an effect. The results are based on the last four days' trials.

Results

A log transformation of the data and an analysis of running times revealed a t of 2.40, $df = 8$, $P < .05$. Group 0_1 ran slower than 0_{30}.

In addition, another point of interest is revealed by the data. Table 2 records the running time for the four critical trials in Exp. IA. The running times of the first four extinction days for Group 30 in Exp. I (Table 1) and the running times of Group 0_{30} in Exp. IA (Table 2) make an interesting comparison. Group 0_{30} is running at least as fast as Group 30. The author can offer no explanation for these data. The *Ss* of Group 30 were given extinction trials directly after acquisition training. Those of Group 0_{30} had 14 extinction trials in the maze stem after acquisition and were then given five additional extinction trials terminating in the goal compartment. Except for the interpolated 14 days of maze-stem extinction for Group 0_{30} these two groups received the same treatment. One would not expect that goal box S^r's would produce such a complete recovery of response strength, even for the four days during which the effect was noted.

TABLE 2

Mean Log Running Time (Sec.) by Days in Exp. IA

Group	Extinction Days				Mean
	2	3	4	5	
0_1	.72	.69	.82	.80	.76
0_{30}	.60	.48	.49	.53	.52

Discussion

If the more molecular analysis is accurate, then *Ss* removed from the goal box very quickly should run more slowly than *Ss* left in the goal box long enough to complete the chain. On the basis of the data in Exp. I and IA, it seems reasonable to conclude that running time during extinction of a straight alley maze habit is a U-shaped function of retention time in the maze goal box.

The theoretical analysis which leads to the prediction of this function is not the only one which might be used. One might legitimately predict the obtained behavior of *Ss* in the longer retention groups on the basis of at least two additional hypotheses. Retention of animals, for the periods mentioned in this study, in the relatively small compartments used, may become aversive. Secondly, *Ss* which are immediately returned to the home cage might be expected to run faster during extinction than *Ss* delayed in the goal box, if handling after a trial or return to home cage is reinforcing. Both of these hypotheses predict results in the same

direction; that *Ss* delayed in the goal box should run more slowly than *Ss* removed quickly. Experiment II was designed to test this prediction with the secondary reinforcing effect experimentally controlled.

Experiment II

Method

Subjects.—The *Ss* were 20 male albino rats weighing 140–160 gm. at the beginning of the study. These *Ss* had all received identical treatment in a simple acquisition and extinction paradigm in a Skinner box prior to this study, but were maze naive.

Apparatus.—The maze of Exp. I was utilized in Exp. II.

Procedure.—The *Ss* were placed on the same deprivation schedule as used in Exp. I and IA. On Days 5 and 6, after 4-days adaptation to the schedule, they were given one trial per day in the maze without the use of retrace doors. Neither these nor any subsequent trials in this experiment were reinforced by water. The *Ss* were removed from the goal compartment within 1 sec. of the closure of the compartment door. Two matched groups of 10 *Ss* each were obtained on the basis of the log running time on these two trials. On the third running day Group C was retained in the goal box for 12 min. at the end of the trial while Group N was retained for 3 sec. The *Ss* continued under these conditions for 14 days; 13 of these daily trials could then be influenced by the conditions.

Results

The mean time for the confinement group over all days was .97 log sec.; for the nonconfinement group the mean was .98 log sec. The difference was not significant ($t = .04$, $df = 9$, $P > .99$).

Discussion

Since the retention treatments in Exp. II are identical with those used in the extreme groups of Exp. I, and no differences are obtained, it seems reasonable to reject the two alternative hypotheses which might account for the second half of the U-shaped extinction function.

It may be concluded that running time during extinction of a straight alley maze response is a U-shaped function of retention time in the goal box at the end of each trial. One would predict that the right arm of the U has an upper limit determined by the running time of a group stopped just short of the goal box compartment. In the present study the maximum retention time used, 12 min., still produced running times significantly faster than the group not permitted goal box access. It would be possible to test longer confinement periods provided adequate controls assured that confinement is not aversive for these longer periods. These results are predictable on the basis of a molecular analysis of *Ss'* behavior utilizing simple secondary reinforcement theory.

Summary

The following predictions are made using secondary reinforcement theory. If, during extinction, groups of rats are confined in a goal box at the end of runs in a linear maze, the running times will increase as the retention interval increases and will reach an upper limit determined by a group stopped just short of the goal box. Using four groups of *Ss* confined for 3 sec., 30 sec., 4 min., and 12 min. and one group stopped just short of the goal box, data in the predicted directions were obtained from all groups except the 3-sec. group. This group was slower, although not significantly so, than the 30-sec. group. A re-examination of the theoretical model indicated that for very short retention periods the function should be U-shaped. The group never having experienced the goal box on extinction was subdivided into two groups, and these *Ss* were given additional extinction trials with access to the goal box for 1 and 30 sec. per trial before removal. The 30-sec. group yielded shorter running times, providing support for the modified prediction.

Hypotheses that the results might have been due to goal box aversiveness as a function of time or differential reinforcement of groups as a function of the delay in return to home cage were tested in a second experiment; neither received support.

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PRIMARY STIMULUS GENERALIZATION IN DISCRIMINATION LEARNING AS A FUNCTION OF NUMBER OF TRIALS AND INCIDENTAL CUE DIFFERENCES[1]

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This is an investigation into the validity of an important hypothesis in S-R behavior theory. The hypothesis states that the total response tendency to a conditioned compound stimulus is some combination of the response tendencies to its constituent stimulus elements. Another way of saying this is that, whenever a stimulus compound becomes associated with a subsequent response, that response becomes a function of each of the separate component elements of the stimulus. In this study each compound stimulus consisted of two elements, a visual cue and an auditory cue. The problem was to determine whether the auditory ready signal, which was only incidentally part of the stimulus compound, could account for a portion of the response to the total stimulus compound. Prediction was that this would be so.

Howells (1944) studied "color-tone synesthesia," and reported that two verbal responses became differentially associated with two distinctive ready-signal auditory cues. This was done by pairing each auditory cue with one of two distinctive color cues on the vast majority (except the test trials) of thousands of training trials. Perhaps so many trials were required to show that the auditory cues could account for differential verbal response because the response alternatives were too distinctive to *S*. Others (Grings & O'Donnell, 1956; McGeoch & Irion, 1952; Saltz, 1953) have suggested that abrupt changes in the situation with the introduction of probe stimuli instigate uncontrolled and disrupting verbal self-instructions. A procedure developed by Gerjuoy (1953) and used by Gerjuoy and Bechtoldt (1955) apparently avoids these difficulties. The procedure uses a three-stimulus successive discrimination problem involving readily confusable stimuli, with the test stimuli being introduced from the beginning of the experiment as an integral part of the training series, and with a response which is both sensitive to the development of generalized response tendencies and relatively insensitive to verbal self-instructions. The present experiment utilizes the essential features of this technique with modifications to permit a study of generalization effects at different stages of practice as a function of incidental cues common to both the training and testing stimuli.

The setting of this experiment was that of a four-stimulus successive discrimination problem in which human *Ss* were trained to make differential spatial responses to three different visual cues. The visual cues (right, middle, and left) and the spatial responses (pointing to the left, to the middle, and the

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TABLE 1

THE FOUR STIMULI AND ASSOCIATED "CORRECT" RESPONSES

Name of Stimulus Compound	Correct Spatial Response (Pointing Toward)	Component Elements of Stimulus	
		Visual Position	Auditory Tone
$Training_1$ (L)	Left	Right	1
$Testing_1$ (M_L)	Middle	Middle	1
$Testing_2$ (M_R)	Middle	Middle	2
$Training_2$ (R)	Right	Left	2

right, respectively) are listed in the second and third columns in Table 1. The *S* was told that an auditory tone ("ready signal") would warn him that a visual cue was about to appear. Each of the four stimuli was a compound of two component elements: the visual position cue and *also* the incidental auditory tone. The two component elements of each stimulus compound are indicated in the third and fourth columns in Table 1. The tones were designed to be quite "incidental" to reduce the likelihood of verbal self-instructions but they are crucial to the test of our hypothesis. The two tones, associated systematically with the left and right visual positions, were expected to acquire the distinctiveness of these side position cues. The association of the two tones with the middle cue constituted the test trials.

Every trial, training or test trial, was followed by a social reward in the event of a correct response or a social punishment in the event of an incorrect response. The learning series was arranged so that the changing response to the test trials could be charted throughout the course of learning.

Hypotheses

1. The first prediction is as follows: the middle cue with the left-position tone was expected to elicit an increasingly similar response to the left cue with the left-position tone; also, with increased practice, the middle cue with the right-position tone was expected to elicit an increasingly similar response to the right cue with the right-position tone. This prediction of an increasing generalized differential response to the two middle (test) stimuli was, of course, conditional upon the development of a differential response to the two side (training) stimuli.

2. The effect upon this first prediction by the tonal-frequency difference between the two tones was also studied. It has been shown (Raben, 1949; Taylor, 1953) that the similarity of cues in a two-stimulus discrimination problem influences the development of a discrimination, measured by the differential speed of running of rats. The present study attempts to investigate, with human *Ss*, the rate of acquisition of differential spatial response tendencies by incidental cues in a four-stimulus discrimination problem as a function of the similarity of the cues. It was therefore predicted that the rate of development and the ultimate size of the generalized differential response would be a direct function of the difference between the two auditory cues in tonal frequency.

METHOD

Subjects.—Seventy-six students from a class in introductory psychology were assigned at random to three experimental groups ($N = 20$) and one control group ($N = 16$). All *Ss* were required to meet the criterion of normal visual acuity defined as reading the 20/20 line on a Snellen Chart with both eyes open (corrective eyeglasses if necessary) from a distance of 20 ft.

Apparatus.—The apparatus was designed to: (*a*) present, after a minimum intertrial waiting period, the compound stimulus consisting of the "ready-signal" auditory cue and the visual cue in a fixed temporal sequence, (*b*) control the time during which a response was allowed, (*c*) give *S* immediate knowledge of results after each response, and (*d*) indicate to *E* the location of the response in terms of linear distance along a curved line. The apparatus is described in more complete detail elsewhere (Gerjuoy, 1953; Gerjuoy & Bechtoldt, 1955; Walder, 1954).

The *S* sat in a chair of adjustable height located at the response end of the apparatus.

His head was held in a fixed but comfortable position facing the visual cue presentation panel at the far end of a light-masking cloth tunnel. The response he was instructed to make was to move with both hands a T-shaped stylus from its holder to a point on a horizontal semicircular response slot of 8-in. radius, and then back to the holder. The holder was 8 in. from all points on the slot and directly in front of *S*.

The *S* held the horizontal part of the T-shaped stylus. Response was made when the bottom tip of the stylus touched one of the 70 $\frac{1}{4}$-in. contacts at the bottom of the response slot. Touching a contact accomplished two things: (*a*) the activation of an informing chime or buzzer (designated by the instructions to mean "correct" and "incorrect," respectively, and thereby acquiring corresponding social reward values) which gave *S* immediate knowledge of results, and (*b*) the lighting of one of the 70 lamps on a panel on *E*'s desk which indicated the contact in the slot touched by *S* on that trial. Each lamp, wired to a contact, was assigned a numeral corresponding to the distance (in linear units of $\frac{1}{4}$ in.) between its contact and the center of the slot. Contacts on *S*'s left of center were assigned negative numerals and those on his right, positive. Thus, *E* recorded the location of *S*'s response on every trial with a maximum error of less than $\frac{1}{4}$ in.

The compound stimulus was composed of a "ready-signal" auditory cue sounding for 2.6 sec. and a visual cue exhibited for 9 sec. A presentation of this compound stimulus followed a minimum intertrial interval of 6.4 sec. The compound stimulus sequence was initiated by the stylus being in its holder, with time intervals controlled by preset Hunter-Brown decade timers. Failure to keep the stylus in its holder before the appearance of the visual cue stopped the sequence which would then begin again at the start of the waiting period only when the tip of the stylus made contact with the bottom of its holder. One and only one response per stimulus presentation was followed by an informing chime or buzzer. In addition, the chime and buzzer circuits were active only during the presentation of the visual cue. Each such stimulus-response sequence constituted one trial.

The auditory cue, a "ready-signal tone," was emitted by an 8-in. speaker mounted in a 12-in. cube infinite baffle. The signal for the speaker was generated by a Hewlett-Packard audio oscillator (Model 200D) coupled to the speaker by a matching transformer. The gain control on the audio oscillator was set at 60; this produced a tone loud enough to penetrate the background masking sound generated by a 12-in. fan. Four tonal frequencies were used as auditory cues: 330, 335, 350, and 365 cps.

The visual cue (resembling a horizontally elongated T, turned upside down) was defined by the position of a vertical bar of light along a horizontal line of light, both projected forward into an opal glass embedded in the visual cue presentation panel 7.5 ft. directly in front of *S*. The vertical bar (1 mm. wide and 1.2 cm. high) rose from one of three points along the horizontal line: the middle; 2 mm. to the left (from *S*'s point of view) of the middle; and 2 mm. to the right of the middle. These visual cues were formed by light cast through a vertical slot cut into a movable metal plate and a horizontal slot cut into a fixed metal plate, both plates being directly behind the opal glass. The light source was a partially masked 15 w. fluorescent light tube 13 in. behind the metal plates. Between trials when the light tube was not illuminated, *E* set the movable plate to one of the three specified positions for the next presentation.

As given in Table 1, the correctness of a response to any stimulus depended on the position of the visual cue alone. A left (from *S*'s point of view) segment of the slot was correct for the right visual cue; a middle segment for the middle cue; and a right segment for the left cue. Because of the position reversal of cue and response, an important terminological statement is included here: the visual cue for which the left response was correct is referred to as L; the cue for which the right response was correct is referred to as R; and the cue for which the middle response was correct is referred to as M.

Since the correct response might be anywhere in one of three segments of the continuous slot, a slight shift in placement clearly observed by *E* but relatively indiscriminable by *S* marks this response as probably being sensitive to generalization effects.

Each *S* responded to five blocks of 36 trials each. Each block was a modified random sequence of the three visual cue positions. Two modifications were used: (*a*) each block included 12 Ls, 12 Ms and 12 Rs, and (*b*) each position was preceded by each of the three positions an equal number of times; i.e., R was preceded by R, by M and by L two times in each block; this was true for M and for L also. In order to make

this possible, one extra trial, the response to which was not included in the analysis, preceded the first recorded trial in each block.

As suggested in Table 1, only two of the four auditory cues referred to above were used for any one *S*; one auditory cue always served as the ready signal to the visual cue L, and the other always served as the ready signal to R. In each of the five blocks, the auditory cue used as L's ready signal was used as a ready signal for six of the Ms, and the other six Ms were assigned R's ready signal. The compound stimulus composed of middle position and left ready signal is referred to as M_L, and M with R's ready signal is referred to as M_R. L and R henceforth refer to the side training compounds, each composed of the position cue and its own auditory ready signal.

The treatment conditions defining the three experimental groups, labeled D_{35}, D_{20}, and D_5 consisted in the frequency difference between the two auditory cues: *Ss* in the D_{35} (difference of 35 cps) group received auditory cues of 330 and 365 cps; *Ss* in the D_{20} group, auditory cues of 330 and 350 cps; and *Ss* in the D_5 group, 330 and 335 cps. The assignment of the higher of the two tones to L and R, constant for any one *S*, was randomized within each treatment group. The control group (D_0) received "two" tones (both 330 cps) of zero difference in frequency.

The basic response data consisted of the numeral of the contact touched by the stylus on each trial. The 12 responses to each of the training stimuli, L and R, and the 6 to each of the testing stimuli, M_L and M_R, were averaged to give four mean response measures for each *S* in each of five blocks of trials. The analyses were performed on the resulting 20 measures for each *S*, 10 arithmetic mean values for each of the two training stimuli and 10 also for each of the two testing stimuli.

Procedure.—Each *S* served individually in a 2-hr. experimental session. The *S*'s visual acuity was tested before he was allowed into the experimental room. If qualified to serve, he was seated comfortably with his head in the headrest and shown how to hold the stylus. The room was then darkened.

He listened to the tape recorded instructions for about 8 min. during which time it is assumed that the major part of the total dark adaptation of the cones took place (Morgan & Stellar, 1950). These instructions included several opportunities for *S* to ask questions and to practice the response. The *S* was told truthfully that the correct response depended upon the position of the "stimulus" (visual cue). He was urged to "explore' from trial to trial all over the response slot for the correct place for each of the different "stimuli." The chime and buzzer were demonstrated and explained. The tonal "ready signal" (auditory cue) was mentioned but not demonstrated.

Each block of trials took about 12 min.; between the blocks a 3-min. rest period was provided. In the rest period *S* was told to let go of the stylus, take his head from the headrest, and relax while listening to music. Before the next block started, he was told to get ready and urged to try new places in the slot if he was still making errors. The rest period instructions and music were administered by the tape recorder in order to maintain control over the timing of the rest period.

At the end of the fifth block of trials, *S* was asked what determined his response to see what solution he would verbalize. (These informal data indicated that only one *S* understood the relevance of the auditory cues.) He was then requested to say nothing about the experiment to anyone and then dismissed.

Results

The development of differential response tendencies to the side training stimuli (R and L) is prerequisite to the predicted generalized differential response to the middle testing stimuli (M_R and M_L, respectively). An analysis of the D_0 data revealed that the spatial discrimination problem was soluble with no difference in auditory cues for the side training stimuli.

An analysis of variance (Type VI, Lindquist, 1953) of the R and L responses of all four treatment groups is summarized in Table 2. A differential response is indicated by the Position (R vs. L) effect and any of its interactions with the Block (stage of practice) and the Difference (size of tonal difference) effects. The three highly reljable ($P < .001$) Position effects indicate that a differential response to R and L changes as practice increases. The insignificant

TABLE 2

ANALYSIS OF VARIANCE OF MEAN RESPONSES TO R AND L BY GROUPS DIFFERING IN LEVEL OF AUDITORY CUE DIFFERENCE (0, 5, 20, 35 CPS)

Source	*df*	*MS*	*F*
Between-*Ss*	75		
Difference (D)	3	93,711	1.96
Error (b)	72	47,911	
Within-*Ss*	684		
Blocks (B)	4	28,549	0.49
Position (P)	1	24,203,173	526.57*
B × P	4	2,031,741	60.02*
B × D	12	9,878	0.17
P × D	3	588,487	12.80*
B × P × D	12	30,894	0.91
$Error_1$ (w)	288	58,223	
$Error_2$ (w)	72	45,964	
$Error_3$ (w)	288	33,851	
Total	759		

* $P < .001$.

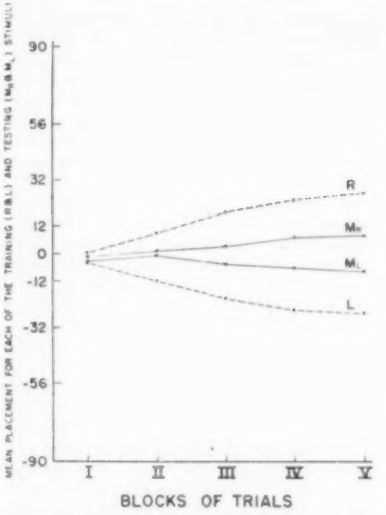

FIG. 1. Development of differential spatial responses to training stimuli R and L with differential generalized responses to testing stimuli M_R and M_L indicated.

triple interaction indicates that the rate of change in differential response is not different for the four treatment groups; the over-all spatial discrimination learning curves are presented by the broken lines in Fig. 1. Finally, the significant Position × Difference effect suggests that the over-all size of the differential response varies from group to group. Table 3 indicates that the magnitude of the mean differential response (R minus L) is a direct monotonic function of the auditory cue difference.

On the basis of the preceding analyses it may be concluded that the spatial discrimination problem was solved by all treatment groups. This provides a basis for expecting the development of generalization effects in the responses to M_R and M_L, the testing stimuli.

Generalization effects.—The analysis of the responses to the middle position stimuli, M_R and M_L, by the three experimental treatment groups (D_5, D_{20}, and D_{35}) constitutes the test of the predicted generalization effects. An analysis of variance, summarized in Table 4, yielded the significant Difference and Block factors which have no bearing on the differential response to the two middle positions. As in the preceding analysis, it is the effects involving position which are of interest here; three such effects reached significance. The change in size of the differential response, sug-

TABLE 3

MEAN RESPONSES AND MEAN DIFFERENTIAL RESPONSES TO STIMULI R AND L BY EACH OF FOUR GROUPS

Level of Auditory Cue Difference in CPS	Mean Responses		Mean Differential Responses (R-L)
	R	L	
0	10.24	−9.33	19.57
5	10.26	−12.94	23.20
20	19.30	−15.34	34.64
35	17.72	−21.80	39.52

TABLE 4

ANALYSIS OF VARIANCE OF MEAN RESPONSES TO M_R AND M_L BY THREE GROUPS DIFFERING IN LEVEL OF AUDITORY CUE DIFFERENCE (5, 20, AND 35 CPS)

Source	*df*	*MS*	*F*
Between-*Ss*	59		
Difference (D)	2	42,318	3.58*
Error (b)	57	11,832	
Within-*Ss*	540		
Block (B)	4	8,120	3.36**
Position (P)	1	332,385	18.27***
B × P	4	45,702	9.35***
B × D	8	2,856	1.18
P × D	2	7,776	0.43
B × P × D	8	9,747	1.99*
$Error_1$ (w)	228	2,419	
$Error_2$ (w)	57	18,189	
$Error_3$ (w)	228	4,890	
Total	599		

* $P < .05$.
** $P < .025$.
*** $P < .001$.

gested by the significant Position and Block × Position effects, is illustrated by the solid trend lines in Fig. 1. Each trend was analyzed separately by a Treatments × *Ss* design (Lindquist, 1953, p. 156ff.); both analyses indicated by their significant Block effects (for the M_R trend, $P < .001$, and for the M_L trend, $P < .05$) that there was a change in response to both stimuli over blocks of trials. Furthermore, the M_L trend was rotated 180° about the *x*-axis, along which the mean placement equals zero, by multiplying all responses to M_L by (-1). The trend test (Lindquist, 1953, pp. 350–351) yielded results consistent with the hypothesis that M_R and $-M_L$ followed the same pattern and were not displaced from one another. This acceptance of the coincidence hypothesis for the half-transformed data is equivalent to the acceptance of the hypothesis that the generalization effects developed symmetrically about the center of the response slot.

The significant triple interaction in Table 4 suggests that the rate of change in differential response to the testing stimuli varies from group to group; Fig. 2 indicates that the rate of development of a generalized differential response is a direct monotonic function of the auditory cue differences.

The major findings, then, are: (*a*) The visual discrimination problem involving the side training stimuli, R and L, was solved by all four treatment groups. (*b*) While the rate of development of this differential response is not a function of auditory cue differences, the over-all size of the differential response varies directly with the tonal differences. (*c*) As the differential response to the training stimuli developed over blocks of trials, so did a similar response develop to the testing stimuli. (*d*) This generalized differential response to the testing stimuli develops at a

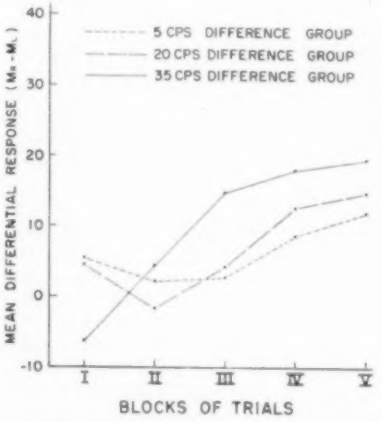

FIG. 2. Development of generalized differential responses to M_R and M_L by each of the three experimental treatment groups (D_5, D_{20}, and D_{35}).

rate which is a direct monotonic function of auditory cue differences.

Discussion

Four stimulus-response connections were trained in the same experimental session to reduce the disruptive effects thought to be associated with the introduction of test trials after an initial training series. While changes in the experimental procedure and in self-instructions may have been avoided, this technique appears subject to complex interstimulus generalization effects. The predictions made at the outset were in terms of the modification of the responses to the middle stimuli as a function of the auditory cues paired with the side stimuli. The obverse prediction could be made also, i.e., that the responses to the side stimuli would be modified as a function of the pairing of these same cues with the middle stimuli. The test of this prediction would involve comparison of these results with experiments in which no middle cues were used. The basis for the assignment of the labels *training* and *testing*, respectively, to the R and L and the M_R and M_L stimuli was that it served terminological convenience and indicated the main interest of this study. Since our interest was in the generalization effects upon the middle stimuli, the auditory cues were paired with the side *training* stimuli twice as often as with the middle *testing* stimuli. Thus, assuming the strength of a response tendency to be a direct function of the number of rewarded responses, it was anticipated that the net response tendency acquired by each auditory cue would be a spatial response somewhere between the midpoint of the rewarded responses to the middle region of the slot and the midpoint of the rewarded responses to the region which was correct for its side training stimulus. In this sense and dependent upon the solution of the visual discrimination problem, the side positions were regarded as the training stimuli.

The first prediction concerning the development of differential spatial response tendencies to the two test stimuli as a function of the incidental auditory cues was confirmed. Since the only difference between the two middle test stimuli was the history of the two auditory cues, it is clear that the auditory cues had acquired the property of evoking response tendencies from their previous association with the side training stimuli. These results are thus consistent with the findings of Howells (1944) and Gerjuoy (1953). It may be noted that the modification of a response by the incidental auditory cues in Howells' study required thousands of training trials. By avoiding the use of a well established, structured response (e.g., color naming) the present experiment was able to show primary stimulus generalization effects after just 60 trials with each of two training stimuli.

Although these results are consistent with those reported by Gerjuoy, the differential generalization effects exhibited by two responses to the same middle position cue as a function of two incidental cues provide more clear-cut support of the hypothesis common to both studies, i.e., that parts of a stimulus compound acquire response potential along with the total stimulus. Thus, in an experiment like this, the whole does not appear to be greater than the sum of its parts.

The results bearing on the second prediction concerning the relationship between size of auditory cue difference and magnitude of the differential response to the testing stimuli were also confirmatory. This relationship appeared as a significant effect with both the training and testing stimuli. This is consistent with previous experimentation (Raben, 1949; Taylor, 1953).

The results obtained in this study have a clear and direct implication for a basic hypothesis within Spence's (1936, 1937, 1952) discrimination theory. The acquisition of reaction potential by parts of a compound stimulus as a function of the previous evocations of a rewarded response by that stimulus constitutes an important principle in his theory.

The present study lends direct support to this principle.

These findings, obtained with human *Ss*, give the theory more general application and lend credence to other attempts to apply stimulus-response theory to the analysis of complex human behavior as exemplified by Dollard and Miller (1950). The fact that a major part of human learning is with verbal symbols is no deterrent to this interpretation, unless verbal and nonverbal responses are assumed to follow different laws. It seems more reasonable to assume that verbal learning behavior is distinguished primarily by the possibility of a wide range of associative connections developed by secondary generalization. The present study, then, can be considered as demonstrating the usefulness of experimental situations in which such variable verbal stimulus-response relations are adequately controlled or minimized.

Summary

The acquisition of response tendencies by parts of a compound stimulus was studied in a four-stimulus visual discrimination problem. The procedure was designed to test the hypotheses in such a way that the possibly disruptive effects of verbal habits of the human *Ss* would be minimized. A generalized differential response, mediated by incidental "ready-signal" auditory cues common to training and testing stimuli, was the criterion measure. The differential response developed as a function of stage of practice and level of auditory cue differences. Support was indicated for attempts to apply S-R theory to human behavior.

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PERCEPTION AND MEDIATION IN CONCEPT LEARNING[1]

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If behavior is represented by S-R associations, one characteristic that distinguishes problem solving from conditioning is the more extended behavioral chains of the former (Kendler, 1961). Better understanding of problem solving behavior will ensue if techniques are developed that enable analysis of the component segments of such chains. The present study is concerned with analyzing a concept learning chain, a simplified version of which is represented in Fig. 1. The chain begins with the stimulus "Ready" as announced by *E* to which *S* responds with a perceptual orienting response (looking to the right or left). This act is

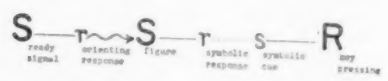

FIG. 1. The hypothesized behavioral chain operating at the time *S* was being shifted to the second concept. Capital letters refer to directly observable stimulus and response events, while small letters refer to those that are inferred.

instrumental in bringing to *S*'s attention a geometrical design to which he, in turn, responds with an implicit response that serves as the cue for the correct key pressing response. It is hypothesized that in the concept learning problems of the sort used in this study, the achievement of a fairly high criterion of learning is accompanied by the adult human *S* making an implicit response (Kendler & D'Amato, 1955) that abstracts the important features of the stimuli to which he is consistently responding. It is primarily to the cue properties of this mediated response that the correct response is associated.

The experimental procedure and design allowed for the independent control of the perceptual and symbolic responses within this chain of events and thus provided knowledge as to how these two segments of a common chain interact.

METHOD

Experimental design.—All *S*s were required to learn two successive concepts. The variables manipulated were the conditions of shifting from the first to the second concept. There were two sets of conditions arranged in a 2 × 2 factorial design.

Half of the *S*s were presented with a reversal shift (i.e., the previously relevant concept remained relevant but the overt concept had to be reversed). The other half were presented with a nonreversal shift (i.e., the previously irrelevant concept became relevant). Previous research has established that college students execute a reversal shift more rapidly than a nonreversal shift (Buss, 1953, 1956; Harrow & Friedman, 1958; Kendler & D'Amato, 1955; Kendler & Mayzner, 1956). An S-R mediational theory (Kendler & D'Amato, 1955) explains the results by postulating that reversal shift *S*s have the advantage of having the appropriate mediational response available at the outset. Only the overt response has to be changed. A successful nonreversal shift requires *S* to adopt a new mediational response and an appropriate overt response. Thus the manipulation of the kind of shift varies, according to this analysis, the availability of the appropriate mediating response.

The other condition involved the manipu-

[1] This study was supported by the Office of Naval Research. Reproduction in whole or in part of this article is permitted for any purpose of the United States Government. Appreciation is expressed to T. S. Kendler for helpful suggestions in preparing the manuscript.

lation of the perceptual orienting[2] response by varying the position of the stimuli which were presented tachistoscopically. Both the reversal (R) and nonreversal (NR) groups were split into two subgroups. For one group (P+) the perceptual orienting response that was appropriate for the learning of the first concept was appropriate also for the second concept. For the remaining *Ss* the stimuli to which they were to respond in the second concept appeared in a different position than did the relevant stimulus during the learning of the first concept. Thus these *Ss* (P−) were required to make an orienting response during the learning of the second concept that was different than the one made while learning the first concept.

Subjects.—The *Ss*, who were randomly assigned to the four experimental groups, were 45 male students from introductory psychology courses at University College of New York University. Five of these *Ss* were eliminated because of their failure to learn the first concept.

Experimental procedure.—The *Ss* sat approximately 13 in. in front of a Translux translucent screen, which was 43½ in. wide and 34½ in. high. A Bell and Howell automatic slide projector, equipped with a Kemlite electronic flash tube, Type 500, was placed 13 ft. 4 in. behind the screen. Attached to the projector was a capacitor tachistoscopic pulser, which allowed figures to be projected on the screen for a duration of 5 msec. In front of *S* were two response keys, one for each hand. Red lamps, controlled by *E*, were beside each key; these lit up when *S* made a correct response.

The slides contained two figures: a circle with a radius in one of four positions (12, 3, 6, or 9 o'clock), and a square with one of four patterns of stripes (vertical, horizontal, left oblique, or right oblique). These figures, when projected, appeared on the right and left side of the screen approximately halfway between the top and bottom. A distance of approximately 29½ in. separated them. The diameter of the projected circle was 3 in. The side of the square was of similar length. Preliminary investigation suggested that it was difficult for some *Ss* and impossible for others to identify both figures of a slide when projected for a duration of only 5 msec. This preliminary work was conducted with *Ss* who were instructed to see both figures in the brief time flash. Reducing the exposure time below 5 msec. prevented some *Ss* from identifying either one of the two figures. It was decided that in the actual experiment where *Ss* were required to pay attention to only one of the two figures, the 5-msec. flash would be sufficiently rapid to prevent *Ss* from viewing both figures, while not being so rapid as to prevent a sizable percentage of *Ss* from learning the first concept.

Two concepts were used in this study: horizontal-vertical (HV) and straight-oblique (SO) (Kendler & Mayzner, 1956). The HV concept required *S* to attend to the circle. The *S* had to press one of the two keys when the radius was at the 12 or 6 o'clock position, and the other response key when the radius was at the 3 or 9 o'clock position. In order to learn the SO concept *S* had to attend to the square. Whenever the stripes were oblique one key had to be pressed. When the lines were parallel to either the base or side of the square the other key had to be pressed.

There were 16 stimulus slides, one for each of the possible combinations of the two stimulus figures. The slides were placed in an automatic slide changer and presented to all *Ss* in the same predetermined order. The *S* was seated in front of the screen and was read the following instructions by *E*.

> You will be given a problem involving the classification of different geometrical designs. Your task will be to classify different designs into one of two categories. You should try to learn the basis of the correct classification procedure as rapidly as possible.
>
> You will be shown a series of geometrical designs that will be briefly flashed on the screen in front of you. Two designs will be flashed on the screen simultaneously, one appearing here (*E* points) and one appearing here (*E* points). When the two designs are flashed, you must press *one* of

[2] Perception, according to an S-R analysis, is concerned with stimulus reception, i.e., what stimulus becomes associated with a response. There are two major ways in which the perceptual mechanism is controlled: (*a*) by *S*'s orienting (observing, attending) responses which exposes his receptors to a limited part of his physical environment (e.g., Wyckoff, 1952), and (*b*) by the structure of the stimulus configuration (i.e., the gestalt) itself. The operations involved in this experiment are limited to orienting responses. Presumably, an experiment, similar to the present one, could be designed in which the perceptual factor could be controlled by keeping the position of the relevant stimulus unchanged but by imbedding it in different stimulus configurations.

these two keys (*E* points). These keys represent the two categories. If you have chosen the correct key, the light will flash on. If you have not chosen the correct key, that is, if you have chosen the incorrect key, no light will flash on. Your task is to discover the system of classification so that every choice you make will be correct. It is up to you to decide whether you need to pay attention to only one or to both designs in order to choose correctly. Let me repeat. You may pay attention to only one design on each trial, or you may pay attention to both designs presented in each trial, depending upon what *you* think is necessary in order to solve the problem. *Under no circumstances* may you press both keys simultaneously. I will alert you by calling "Ready" just before each presentation. From time to time a pause will be necessary, for example, as when changing slide trays. When this happens, I will notify you by calling "Time." Any questions?

The stimuli were presented with an exposure time of 5 msec. An intertrial interval of 20 sec. was employed.

Half of the *Ss* initially learned the HV concept, while the remaining *Ss* acquired the SO concept. Half of the *Ss* who learned each concept received a reversal shift; i.e., they had to learn to press the key that had previously been incorrect for that particular stimulus figure. The remaining half was subjected to a nonreversal shift. If initially they had to learn the HV concept, they now had to learn the SO concept. For half of all *Ss* the relevant stimulus figure was in the same position before and after the shift. For the other half the relevant stimulus figure would be on one side for one concept and on the other side for the other concept.

The transition from the first concept to the second was made without informing *Ss* of any change in the scoring procedure. Since it was necessary to use new slides for *Ss* who had the position of the stimuli reversed, a tray of slides was inserted into the projector for *all Ss* after reaching the criterion of learning the first concept. In order to prevent *S* from interpreting the introduction of a new tray of slides as a change in experimental procedure, the first four slides were similar to the ones used during the learning of the first concept. They were also scored according to the rules that prevailed during the learning of the first concept.

The slides were presented in an order designed to preclude sequential learning. In order to reduce partial reinforcement effects during the nonreversal shift, the first two slides of the second concept were selected so that a previously correct response would now be wrong.

The criterion of learning for both the first and second concepts was 15 successive correct responses. The *Ss* were allowed a maximum of 128 trials to learn the first concept. The *Ss* who failed to learn the first concept during that time were eliminated from the experiment. The *Ss* who failed to learn the second concept within 128 trials were assigned a score of 128.

Results

The response measure for learning each concept was the number of trials to reach the performance criterion. The criterion trials were not included.

Because of the marked skewness of the learning scores for both concepts and the tendency towards bimodality in the learning scores of the second concept (two *Ss* each in Groups R:P−, NR:P+, NR:P− failed to learn the second concept and hence were assigned scores of 128), a Kruskal-Wallis one-way analysis of variance of sum of ranks was used. No significant differences existed between groups or between concepts (SO vs. HV) in the learning of the first concept.

The learning of the second concept also failed to reveal any difference between the acquisition rate of the two concepts. There were, as Table 1 indicates, differences among the four

TABLE 1

Mean and Median Number of Trials to Learn Second Concept

Group	Mean	*SD*	Median	Range	ΣRanks
R:P+	4.7	4.9	2.5	1–18	87.5
R:P−	45.6	47.8	19.0	3–128	235.5
NR:P+	41.4	46.0	17.5	3–128	241.0
NR:P−	50.0	46.6	25.5	13–128	256.0

experimental groups in the speed of learning the second concept. A Kruskal-Wallis analysis revealed that the differences among the four grou, were significant at the .01 leve,. This significant variation is largely due to the efficient performance of Group R:P+. A Mann-Whitney *U* test revealed that the performance of Group R:P+ was significantly superior at the .002 level (two-tailed test) to each of the three remaining groups. None of these groups differed significantly from each other.

Discussion

The superiority of the R:P+ group over the others is consistent with the present analysis since it is the only one of the four groups that had both the appropriate perceptual and mediating responses at the time of the shift. The *Ss* in the remaining groups had either or both inappropriate perceptual responses or inappropriate mediating responses.

The *Ss* in Group R:P+ executed the shift very rapidly; some *Ss* made only one error while the median number for the entire group was 2.5. How was this accomplished? Obviously neither the entire chain nor the terminal key pressing response appropriate to the first concept undergoes any extended extinction series. It is proposed that the rapid adoption by Group R:P+ of the new key pressing responses is due to the operation of a behavioral chain in addition to the one described in Fig. 1. The first nonreinforcement sets off a chain, the consequence of which is to select the key response other than the one that was previously correct. This might result from a logical decision of some *Ss* to change their response, or the unexpected nonreinforcement confuses *S*, so that he mistakenly depresses the now-correct key (the previously incorrect key) for the postshift concept. The important point, however, is that the new key pressing response occurs contiguously with the implicit mediational response appropriate to a reversal shift. As a result a new association is formed between the old implicit cue and the new key pressing response.

In essence, what is being stated is hat *Ss* in Group R:P+ do not make the first correct postshift response because of their adopting the principle underlying a reversal shift. Instead, it is assumed that processes are operating which encourage the selection of the correct response while an implicit cue appropriate to a reversal shift is operating. The contiguous occurrence of these two followed by reinforcement encourages the adoption of the key pressing responses necessary for a reversal shift. This sort of an analysis has been described (Kendler & Mayzner, 1956) as "sort of a James-Lange theory of problem solving; one makes the overt correct . . . response and if the appropriate symbolic cue is present, then problem solution will occur" (p. 247). Equally applicable to the present results is Guthrie's (1959) statement: "*What is being noticed becomes a signal for what is being done*" (p. 186).

In short, then, the hypothesis is being offered that the rapid shifting behavior of Group R:P+ is due to contiguous occurrence of an implicit cue and an overt response which are themselves segments from different behavior chains. This phenomenon may be likened to the associative shifting which occurs in classical conditioning, e.g., the stimulus (tone) of one association becomes connected to the response (salivation) of another. Underwood (1952), too, has emphasized the importance of contiguity in experience in problem solving. The present results with their interpretation stress the role played by implicit cues and their adventitious occurrence with the appropriate overt response.

So far, the analysis of the experimental findings has been restricted to the discussion of the one group (R:P+) whose performance was superior to the remaining three groups. The behavior of these remaining groups can be analyzed in a manner similar to what has been done for Group R:P+. Appropriate postshift behavior requires for all

Ss a sequence of a correct perceptual act, an appropriate implicit response, and a correct key pressing response. The inferior performances of Groups R:P−, NR:P+, and NR:P− can all be attributed to their difficulty in synchronizing the appropriate perceptual and mediating responses.

Group R:P− in order to execute the reversal shift must acquire a new perceptual orienting response. The great variability of the scores of *Ss* in this group would suggest the acquisition of the new perceptual orienting response, while retaining the old implicit response (it is likely, if not probable, that the evocation of the appropriate mediating response is not entirely dependent on the appropriate orienting response), was relatively simple for some *Ss*. For others the task was much more difficult. Presumably the correct implicit response was extinguished before *S* acquired an appropriate orienting response.

Groups NR:P+ and NR:P− at the time of the shift also possess inappropriate links in their behavior chains. The advantage of having an appropriate perceptual response in a nonreversal shift would seem to be practically negligible if we are to judge by the lack of significance between the scores of Groups NR:P+ and NR:P− (the advantage was slightly in favor of the former). This lack of a significant difference also points to the importance of synchronizing both the perceptual and mediational responses. Without one the occurrence of the other is of little use in the present experiment for obtaining reinforcements consistently, the reason being that the occurrence of one without the other is no guarantee that the appropriate segment (either perceptual or mediational) will persist until the time that the inappropriate segment will be supplanted by the correct one.

Concept learning of the sort occurring in the present study has been represented by a behavioral chain involving perceptual and mediational segments with a final overt (key pressing) response. It has been postulated that the chain necessary for concept learning can be formed by the appropriate perceptual and mediational responses occurring adventitiously with the appropriate overt response. The independent nature of both the perceptual and mediational responses has been noted and the importance of their synchronized occurrence has been emphasized. Of major importance is the fact that the present methodology is capable of experimental variations and modifications that would allow more analytical studies which would assist in the elaboration of this microgenetic analysis. What is needed are studies designed to throw more light upon the (*a*) independent variation of the perceptual and mediational responses, (*b*) the linguistic processes underlying the mediational response, (*c*) the nature of the independent behavior chain that results in the correct key pressing response, and (*d*) the time relationships involved in the synchronizing of the perceptual and mediational responses.

Summary

The influence of a perceptual orienting act and an implicit symbolic response on concept learning was investigated. College students were subjected to two successive concept learning tasks. Two physically discrete and spatially separate stimulus patterns were projected on a screen at such a rapid rate that only one could be perceived on any trial. During the learning of each concept *S* had to pay attention to the relevant stimulus pattern while ignoring the irrelevant one. After learning the first concept half of the *Ss* were required to make a reversal shift (R), while the remaining *Ss* received a nonreversal shift (NR). For half of the *Ss* in each of these two groups the position of the relevant stimulus pattern remained unchanged during the learning of the two concepts (P+). The remaining *Ss* had to shift their perceptual orienting act (P−) when learning the second concept. The results indicated that both factors (the type of shift and the position of the relevant stimulus pattern) influenced the course of learning the second concept. The reversal *Ss* who had the position of the relevant stimulus unchanged (R:P+) learned the second concept significantly faster than the other

three groups (R:P−, NR:P+, and NR:P−). The results were analyzed in terms of a behavioral chain involving a perceptual orienting act, an implicit symbolic response, and a final overt response. The superiority of Group R:P+ was attributed to (*a*) the ease in which the appropriate perceptual and implicit symbolic responses were synchronized, and (*b*) the adventitious occurrence of the correct overt response (key pressing) with the appropriate implicit cue.

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ERRATUM

In the article "Facilitation of Concept Formation through Mediated Generalization" by S. A. Mednick and J. L. Freedman (*J. exp. Psychol.*, 1960, **60,** 278–283) the entry in Table 1 (p. 279) under Paired-Associate List II in the column labeled Pair should read "grape-loud" (instead of "loud-soft").

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SUPPLEMENTARY REPORT: THE EFFECTS OF PROBLEM LENGTH ON TRANSFER DURING LEARNING-SET PERFORMANCE

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A recent investigation of object-discrimination learning set by Levine, Levinson, and Harlow (1959) compared several groups each of which received a different number of trials per problem (tr/p) throughout the experiment. The results suggested the following generalization: From 3 to 12 tr/p learning-set development depends upon the total number of trials presented and does not vary with the way these trials are divided into problems.

Since this generalization is simply the retention of the null hypothesis further testing was deemed important. The generalization implies that performance following a given number of trials (e.g., 12 trials) would be the same no matter how the trials had been arranged into problems (e.g., into four 3-trial problems, two 6-trial problems, or one 12-trial problem). This implication was tested in the present experiment.

Method.—The apparatus, stimulus objects, and stimulus presentation procedure were the same as those used in the previous study. Nine rhesus monkeys, all approximately 2 yr. of age, received two blocks of 20 daily experimental sessions. Prior to the first block and between the two blocks *Ss* took part in an experiment on the effects of confounding position and object cues. It was reasonable to assume that this intervening experiment would have no differential effect on the variable of the present experiment.

Each experimental session lasted for approximately 0.5 hr. and consisted of 36 trials divided into three 12-trial sets. One set consisted of four 3-trial problems, another of two 6-trial problems, and the third of one 12-trial problem. The three sets were presented without special breaks within each session and were varied in order of presentation from session to session.

Results.—The critical results consist in the relative amounts of transfer following the three conditions. This transfer effect could be estimated by inspecting performance on Trial 2 of the problem immediately following each 12-trial set, grouping these second trials according to the condition which they followed and comparing these three groups of scores. This tabulation of Trial 2 performance following the three conditions was made for the two 20-day blocks. An analysis of variance of these data permitted a test of the Between-Conditions variance against the *Ss* × Conditions × Blocks variance. For both the data following an arcsin transformation and for the untransformed data the differences in Trial 2 performance following the three conditions were not significant at even the .10 level. Similar analyses were also made of the performance on Trial 3. The results of these tests, too, were not significant. In general, the only variances which were significant, and that in all the analyses, were the Between-*Ss* and the Between-Blocks variances.

Discussion.—The effects of dividing a given number of trials in an object-discrimination learning-set experiment into different numbers of problems has now been investigated in two ways. In the study by Levine et al. (1959) the cumulative effect, i.e., the effects on the overall learning-set functions, of different numbers of tr/p was determined. In the present study the transfer of learning from a given tr/p condition to the immediately following problem was evaluated. Both studies suggest the same generalization: From 3 to 12 tr/p learning-set performance depends upon the number of trials presented and does not vary with the way these trials are divided into problems.

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